Methane Hydrate Production from Alaskan Permafrost

Technical Progress Report

April 1, 2003 to June 30, 2003

by

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Disclaimer

Abstract

Natural-gas hydrates have been encountered beneath the permafrost and considered a nuisance by the oil and gas industry for years. Engineers working in Russia, Canada and the USA have documented numerous drilling problems, including kicks and uncontrolled gas releases, in arctic regions. Information has been generated in laboratory studies pertaining to the extent, volume, chemistry and phase behavior of gas hydrates. Scientists studying hydrate potential agree that the potential is great – on the North Slope of Alaska alone, it has been estimated at 590 TCF. However, little information has been obtained on physical samples taken from actual rock containing hydrates.

This gas-hydrate project is in the second year of a three-year endeavor being sponsored by Maurer Technology, Noble, and Anadarko Petroleum, in partnership with the DOE. The purpose of the project is to build on previous and ongoing R&D in the area of onshore hydrate deposition. We plan to identify, quantify and predict production potential for hydrates located on the North Slope of Alaska. We also plan to design and implement a program to safely and economically drill, core and produce gas from arctic hydrates.

The current work scope is to drill and core a well on Anadarko leases in FY 2003. We are also using an on-site core analysis laboratory to determine some of the physical characteristics of the hydrates and surrounding rock. The well is being drilled from a new Anadarko Arctic Platform that will have minimal footprint and environmental impact. We hope to correlate geology, geophysics, logs, and drilling and production data to allow reservoir models to be calibrated. Ultimately, our goal is to form an objective technical and economic evaluation of reservoir potential in Alaska.

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1. Introduction

The purpose of this project is to plan, design and implement a program that will safely and economically drill/core and produce natural gas from arctic hydrates. A significant amount of research has been conducted on naturally occurring gas hydrates, and our team (Maurer, Anadarko and Noble) will adapt and apply laboratory R&D and technology in the field.

This is an aggressive project that will identify, quantify and predict production potential of hydrates by drilling the first dedicated hydrate well on the North Slope of Alaska in an area with hydrate potential. This project will use an Anadarko special purpose on-site laboratory to help analyze hydrate cores. Additionally, the well will be drilled from a special purpose-built arctic platform. Data generated in this project will also assist research organizations and technical teams as we begin to make an objective technical and economic assessment of this promising natural gas reservoir potential.

2. Executive Summary

Objectives and Scope of Work

The objectives of this gas-hydrate project are to analyze existing geological and geophysical data and obtain new field data required to predict hydrate occurrences; to test the best methods and tools for drilling and recovering hydrates; and to plan, design, and implement a program to safely and economically drill and produce gas from hydrates in Alaska.

The overall Scope of Work is to:

1. Evaluate geological and geophysical data that aid in delineation of hydrate prospects
2. Evaluate existing best technology to drill, complete and produce gas hydrates
3. Develop a plan to drill, core, test and instrument gas-hydrate wells in Northern Alaska
4. Characterize the resource through geophysics, logging, engineering and geological core and fluids analysis
5. Test and then monitor gas production from hydrate wells for one year
6. Quantify models/simulators with data for estimating ultimate recovery potential
7. Learn how to identify favorable stratigraphic intervals that enhance methane production
8. Assess commercial viability of developing this resource and ultimately develop a long-term production plan
9. Provide real hydrate core samples for laboratory testing
10. Develop and test physical and chemical methods to stabilize hydrate wellbores and improve core recovery
11. Step outside the well-known Prudhoe Bay/Kuparuk River area to further delineate hydrate deposits in Alaska
12. Report results to the DOE and transfer technology to the Industry

Phase I has been completed, which included well planning, site selection and equipment construction.

Phase II Participants:

Maurer Technology Inc. – Project coordination, project management and DRC testing

Anadarko Petroleum Corporation – Overall project management for the design, construction, and operation of the Arctic Drilling Platform, the mobile core lab, and the field coring operations.

Noble Engineering and Development – Provided personnel and real-time data collection and transmitted digital data and video to project participants located offsite and wellsite drilling personnel.

University of Alaska – Supports studies on geology, tundra, and produced water disposal.

Lawrence Berkley National Lab (LBNL) - Reservoir modeling used for well test planning and onsite portable X-ray scanner with wellsite operator.

Sandia National Lab – Provided downhole mud pressure and temperature recording tool.

Pacific National Lab (PNL) – Provided portable infrared scanner.

United States Geological Survey (USGS) – Provided synthetic core for drilling tests, phase behavior model for hydrates, pressure vessels for hydrate core storage and technical advice. Modeling of hydrate preservation and dissociation. Provided personnel for coal core and analysis.

Schlumberger Oilfield Services – Provided CMR equipment used in mobile core lab and two onsite analysts; and well-logging services.

Paulsson Geophysical Services – Scheduled for vertical seismic profiling.

Advisory Board – Craig Woolard, University of Alaska, Anchorage; Steve Bartz, Schlumberger; Steve Kirby, USGS; Tim Collette, USGS; Theresa Imm, Arctic Slope Regional Commission; C. Sondergeld, University of Oklahoma; Richard Miller, University of Kansas; and David Young, Baker Hughes Inteq.

Accomplishments

- Design and construction of Anadarko's Mobile Core Laboratory completed in August 2002. This lab permits cores to be maintained and analyzed at a reduced temperature and in close proximity to the drill site.

- Operational and logistics planning, geology and geophysics analysis, and site selection completed and environmental and operations permits obtained by the end of December 2002.

- Anadarko's Arctic Platform was installed in February 2003. Technology being tested here could help to achieve three goals independent of this project:

  - allow operators to work outside the present operations season

  - provide access to remote areas where water to build ice roads is scarce and steep grades make it difficult to set or supply a drilling rig

  - reduce the environmental impact of a well location on the tundra

- Arctic Platform topside facilities were set during March 2003.

- Hot Ice #1 Well was spudded March 31, 2003.

- Well cored, logged and cased to the base of the permafrost during April 2003.

The Hot Ice No. 1 well is located approximately 20 miles south of the Kuparuk River oil field center and about 40 miles southwest of Prudhoe Bay. Based on evidence from nearby offsets in the Cirque and Tarn gas hydrate accumulations, hydrates are expected to be found in sands near the base of the permafrost. The well was spudded on March 31, 2003, and was continuously cored from a depth of 107 feet to 1400 feet (RKB) with core recovery of 93%. The base of the permafrost was crossed at about 1250 ft. Open-hole logs were acquired and 7-inch casing set in a shale zone between the Ugnu and West Sak formations.

Current Status and Remaining Tasks

Operations on the Hot Ice well are currently suspended pending the return of cold weather. Anadarko is committed to resume coring operations in the fourth quarter of 2003, prior to the opening of the conventional operations season. Casing was set directly above the West Sak formation. A sand accumulation at the top of the West Sak should provide a good chance to encounter hydrates. After operations recommence, the hydrate stability interval will be cored, approximately to 2200-2400 feet (670-732 meters) deep. After total depth is reached and the well ID logged, depending on the amount of hydrates encountered, a final completion program will be formulated.

The complete set of core, well log, production and downhole pressure and temperature data will be made available for use in evaluating the hydrate reservoir's quality and to determine potential for production from arctic hydrate intervals. The data will be incorporated into hydrate reservoir models to test possible scenarios for producing methane from hydrates in similar settings.

A number of other officials from the State of Alaska, the U.S. Department of Interior and the Department of Energy visited the site.

DOE NETL has also established a special web page for references to their support of gas-hydrate development. At their site (http://www.netl.doe.gov/scng/hydrate/) are posted updates describing the Hot Ice project as well as the latest version of “Fire in the Ice,” the National Energy Technology Laboratory Methane Hydrate Newsletter. The most recent version of the newsletter is Spring 2003.

Drilling the Hot Ice No. 1 well marked the first test of Anadarko’s Arctic Platform. The primary platform consists of 16 lightweight aluminum modules fitted together and mounted on steel legs 12 feet above the ground surface. The platform is large enough to contain a coring rig, auxiliary equipment, mud tanks, and the mobile core analysis laboratory. Another five modules form an adjacent platform with living quarters for 40 people.

The Hot Ice No. 1 well was cored with a wireline retrievable coring system using drilling mud that had been chilled to 23°F (-5°C) to preserve the 3.3-inch (8.5-cm) core and to prevent any hydrate from dissociating during core recovery. The mobile core laboratory was employed to immediately perform measurements on both whole core and 1-inch plugs taken from the whole core, while maintaining that temperature. Whole core measurements included: core gamma log, infrared temperature, velocity measurement, geologic description and white light photographs, high resolution CT scan (equipment from LBNL), and a nuclear magnetic resonance measurement (with CMR tool from Schlumberger) on a portion of each section of core. Plug measurements included: bulk volume, grain density, helium porosity and permeability at confining stress, P and S wave velocity, resistivity, and thermal conductivity. For hydrate samples, the NMR system (Schlumberger CMR Tool) is used to determine the fluid volume in the sample at various steps in the dissociation process, while released gas volumes and composition are also recorded.

The well was suspended on April 21, 2003 due to unseasonably warm conditions that prevented transport of heavy loads over the tundra. The mobile core lab and collected core were moved to Deadhorse, Alaska, to permit continuation of core analysis.

3. Experimental

3.1 BACKGROUND

Figure 1.
Methane Hydrate

Natural-gas hydrates (**Figure 1**) beneath the permafrost have been encountered by the oil and gas industry for years. Numerous drilling problems, including gas kicks and uncontrolled gas releases, have been well documented in the arctic regions by Russian, USA and Canadian engineers. There has been a significant volume of scientific information generated in laboratory studies over the past decade as to the extent, volume, chemistry and phase behavior of gas hydrates. However, virtually all of this information was obtained on hydrate samples created in the laboratory, not samples from the field.

Discovery of large accumulations around the world (**Figure 2**) has confirmed that gas hydrates may represent a significant energy source. Publications (Makogon and others) on the Messoyakhi gas-hydrate production in Siberia (which has produced since 1965), document that the potential for gas-hydrate production exists. Several studies have also addressed the potential for gas hydrates in the permafrost regions of North America. The results from the Mallik Hydrate, Mackenzie Delta Northwest Territories, Canada wells (hereafter, the "Mallik wells") drilled by JAPEX, JNOC and GSC, provide a significant amount of useful background information. The USGS made sizeable contributions to the Mallik project, as well as many other investigations on gas hydrates in the USA (especially Alaska), and has a tremendous amount of basic information on the presence and behavior of hydrates.

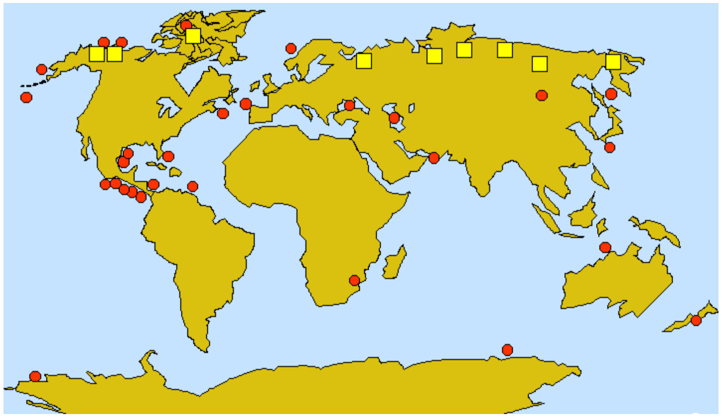


Figure 2. Methane Hydrate Deposits (USGS)

The project team now believes it is time to apply this knowledge to environmentally sound development of this resource. The first critical step is to drill and monitor wells in regions in the USA with the greatest likelihood of commercial quantities of methane hydrates. In fact, the project work represents the first attempt to drill, core and monitor hydrate wells in the USA. The specific objective of this effort is to obtain the field data required to verify geological, geophysical and geochemical models of hydrates and to plan, design and implement a program to safely and economically drill and produce gas from arctic hydrates. These "ground truth" data did not previously exist.

North America's emphasis on utilizing clean-burning natural gas for power generation has increased demand for gas and resulted in higher gas prices. A number of forecasts, including the NPC Study on Natural Gas (2000), indicate higher demand with prices in the range of $4 to $8/mcf. This is sufficiently high to allow investments in sources previously deemed uneconomic. The projected US demand for natural gas may grow to nearly 30 TCF by the end of the decade. This demand, particularly on the West Coast of the US, strongly suggests that a proposed Alaska Natural Gas Pipeline may now be economically feasible. This pending pipeline should provide a commercial market for natural gas, thereby allowing the necessary investments in new technology to develop and market the hydrate resource.

Anadarko is the one of the largest independent oil and gas exploration and production companies in the world, with 6.1 TCF of gas reserves and 1046 MMBO of oil reserves (more than 2 BBOE). Domestically, it has operations in Texas, Louisiana, the Mid-Continent and Rocky Mountains, Alaska and the Gulf of Mexico. Anadarko, one of the most active drillers in North America, is balancing its current exploration and production programs by investing in developing new gas resources in North America, including areas where the risks and potential rewards are high with the application of advanced technology. It is now one of the largest leaseholders in Alaska, with an ambitious program of exploratory drilling and seismic studies. Anadarko holds nearly 500,000 undeveloped acres under lease, many with the potential for commercial production from hydrates. Anadarko also has extensive holdings in the Mackenzie Delta region of the Northwest Territories of Canada, which also hold potential for hydrates. Thus, Anadarko is very interested in developing this resource.

With the amount of information on hydrates now available and the potential of developing this huge resource, this project makes good economic sense at this time. The best resources and ideas from around the world will be used to implement the technology in the field. Thorough planning of the test wells should allow avoiding some of the problems encountered in previous gas-hydrate wells.

This project will provide valuable information to the DOE, industry, and research community to identify key barriers and problems related to gas-hydrate exploration and production. This information will be highly useful in developing innovative, cost-effective methods to overcome these barriers. Close interaction will be maintained with an Advisory Board that includes Teresa Imm, Arctic Slope Regional Corp., Craig Woolard, University of Alaska Anchorage, Steve Kirby, USGS, Steve Bartz, Schlumberger, Timothy Colette, USGS, David Young, Baker Hughes Inteq, Rick Miller, Kansas Geological Survey, and Carl Sondergeld, University of Oklahoma.

3.2 OBJECTIVES

The objectives of this gas-hydrate project are to:

1. Analyze existing geological and geophysical data and obtain new field data required to predict hydrate occurrences

2. Test the best methods and tools for drilling and recovering hydrates
3. Plan, design, and implement a program to safely and economically drill and produce gas from hydrates.

3.3 SCOPE OF WORK

The overall scope of the work for this Alaskan Hydrates project is to:

1. Evaluate geological and geophysical data that aid in delineation of hydrate prospects
2. Evaluate existing best technology to drill, complete and produce gas hydrates
3. Develop a plan to drill, core, test and instrument a gas-hydrate well in Northern Alaska
4. Characterize the resource through geophysics, logging, engineering and geological core and fluids analysis
5. Test and then monitor gas production from the hydrate wells for an extended period of time.
6. Quantify models/simulators with data for estimating ultimate recovery potential
7. Learn how to identify favorable stratigraphic intervals that enhance methane production
8. Assess commercial viability of developing this resource and ultimately develop a long-term production plan
9. Provide real hydrate core samples for laboratory testing
10. Develop and test physical and chemical methods to stabilize hydrate wellbores and improve core recovery
11. Step outside the well-known Prudhoe Bay/Kuparuk River area to further delineate hydrate deposits in Alaska
12. Report results to the DOE and transfer technology to the Industry

4. Results and Discussion

4.1 DELIVERABLES

During **Phase I**, an effective plan was developed for drilling new hydrate wells in Alaska. This included geological and geophysical assessment, site selection, and developing well plans.

In separate reports the project team provided DOE with the following Phase I Deliverables:

- Digital map of well locations
- Well log correlation sections
- Seismic maps and sections showing stratigraphic and lithologic units within gas hydrate stability zone
- Reservoir modeling report
- Well data for control wells used for site selection
- Site selection plan
- Testing and analytical procedures (Topical Report)
- Well plan
- Permit application
- NEPA requirements

Additional Phase I achievements beyond the original contract obligations were also delivered. These include:

- Topical reports from University of Oklahoma and the Drilling Research Center on hydrate core apparatus and testing
- Support of other DOE hydrate projects including the Westport Core Handling Manual

- Three reports from the University of Alaska Anchorage
    1. Geological Research of Well Records
    2. Water Generated during Production of Gas Hydrates
    3. Permafrost Foundations/Suitability of Tundra Platform Legs
- USGS report on dissociation of hydrates at elevated pressures
- LBNL Report on Hydrate Preservation in Cores
- Arctic Platform Video
- National Press Release and Conference in Washington DC
- First-ever North Slope coal cores provided to the USGS for coalbed methane study
- New equipment for measuring hydrates

Phase II encompasses drilling/coring a new hydrate well. After drilling, the well will be thoroughly logged and tested. Core will be analyzed on site using an innovative mobile laboratory. After completion, shallow seismic will be shot. The wells will then be monitored for an extended period and assessed for production potential. An advanced hydrates simulator will be calibrated with field data and used in the development of economic and production models for these and other hydrate accumulations.

4.2 TEAM ORGANIZATION

Team organization is shown in Figure 3.

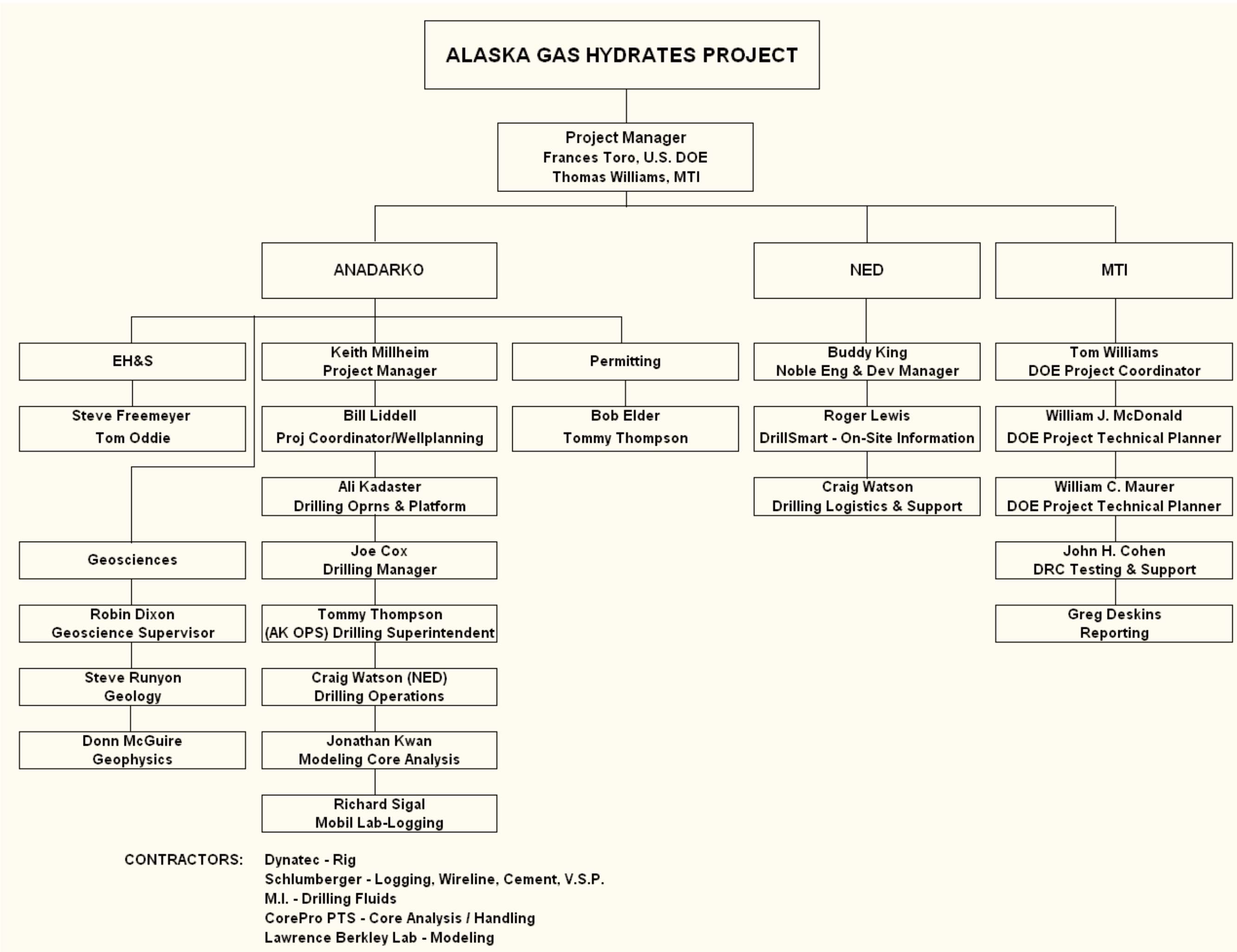


Figure 3. Project Team Structure

4.3 ACCOMPLISHMENTS

PHASE I

Phase I is now complete. Tasks 1-7 were completed as shown in the Phase I schedule in **Figure 4**.

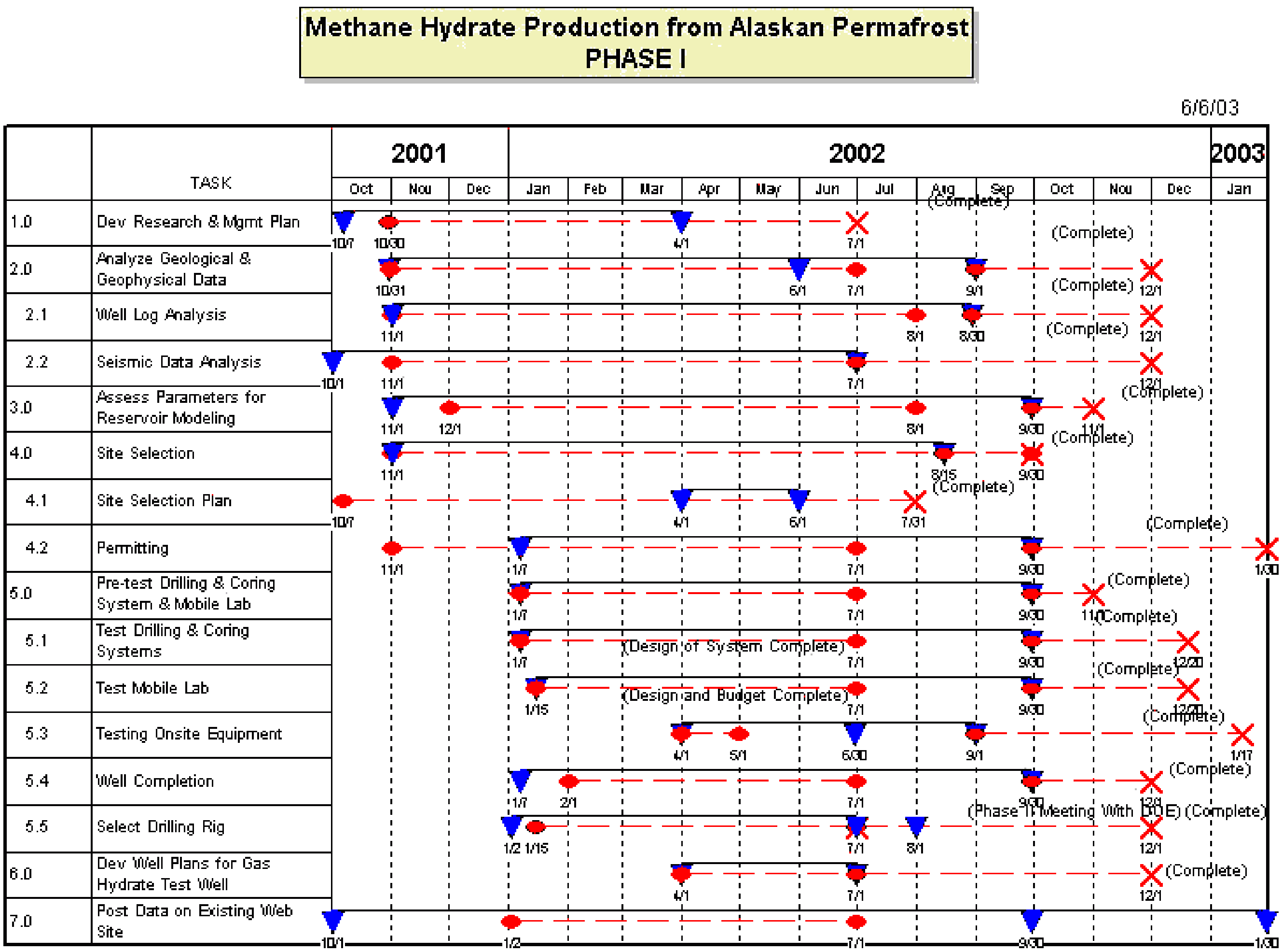


Figure 4. Phase I Project Schedule

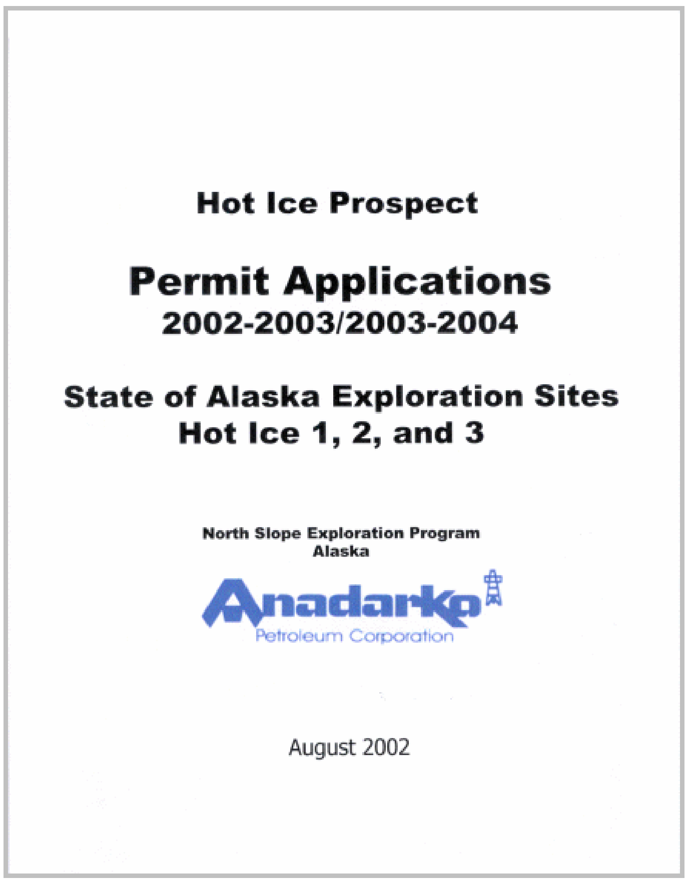
Phase I Task Activities that Continue into Phase II

A “lessons learned” workshop was held at Anadarko’s office in the Woodlands on June 12–17, 2003. Each activity and task were reviewed and a budget revision was completed. The cost of the unanticipated demobilization and stand-by fees have significantly increased the cost of the project.

Subtask 4.2 – Permitting

Permitting was completed; however revisions for re-mobilization prior to the normal drilling season (due to freezing of the permafrost) are on-going. Permitting the VSP is currently an issue. The platform has not moved due to thawing this summer and It is anticipated Anadarko will be allowed on the well early. Three wells were initially permitted, named Hot Ice #1, #2 and #3 (HOT ICE = High Output Technology Innovatively Chasing Energy). Following the Anadarko Geological and Geophysical assessment and the Site Selection task, the best location was selected in November and final permitting activity has focused on this location for HOT ICE #1. With the addition of the Arctic Platform, new permitting activities and costs have been required. Meetings with and inspections by State and Federal regulators have continued. A number of positive reports complimentary of the operation have resulted.

The permit application was provided to the DOE (see below)



Hot Ice Prospect

Permit Applications
2002-2003/2003-2004

State of Alaska Exploration Sites
Hot Ice 1, 2, and 3

North Slope Exploration Program
Alaska

Anadarko
Petroleum Corporation

August 2002

A recent map showing the location of the site is presented in **Figure 5**.

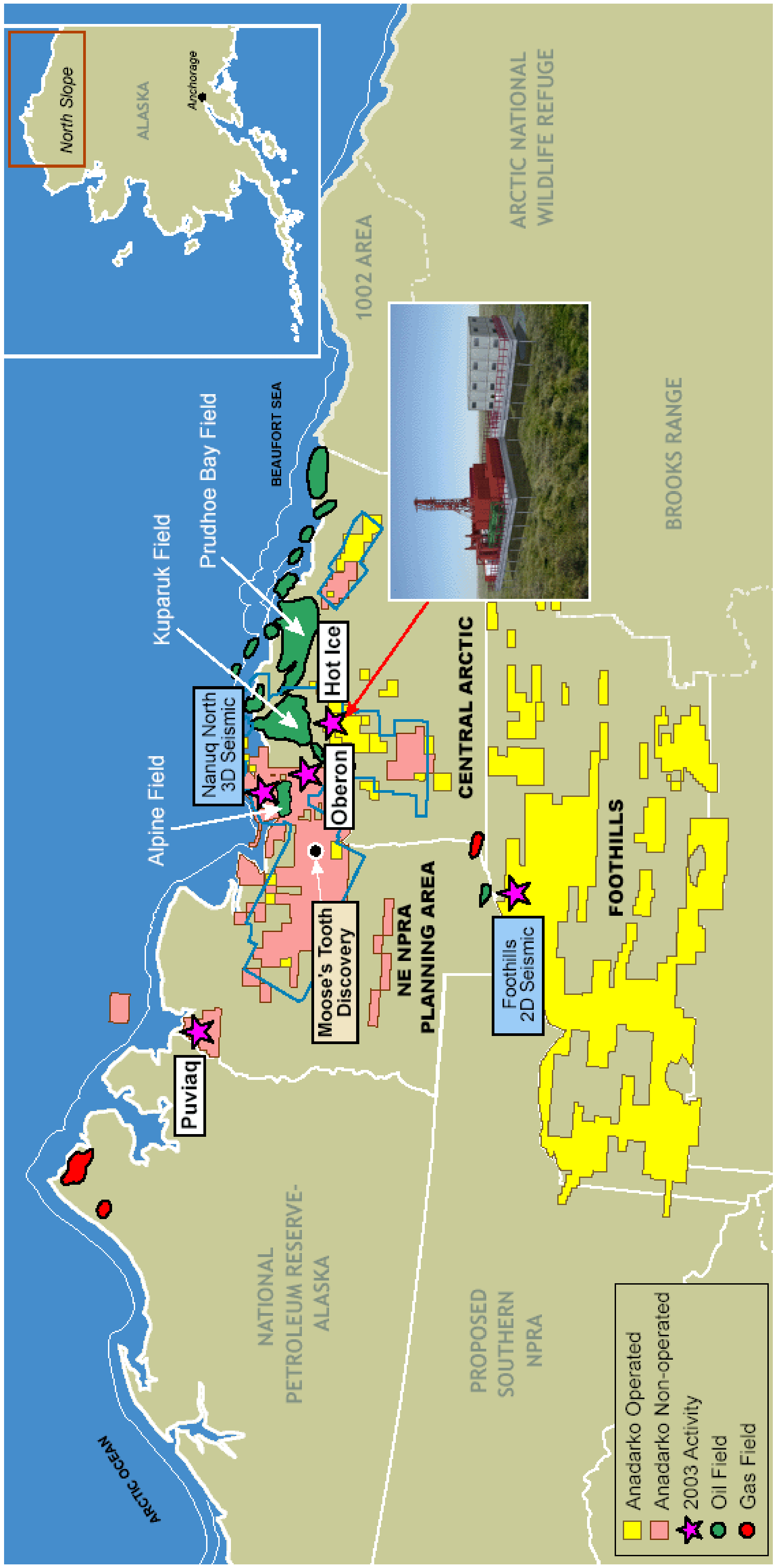


Figure 5. Map of North Slope Showing Location of Hot Ice #1

Task 7.0 – Posting Data on Existing Web Sites

Maurer constructed an Internet web site (http://www.maurertechnology.com/index-hydrates.html) for hydrate project updates. It is linked to the NETL hydrate web site and displays presentations, progress highlights and photos. This site will continue to be updated to make results available to the R&D community. Special information is available to the project team (including DOE) through a password-protected page. Information about our project is being exchanged with other hydrate research organizations and meetings. Press releases have been issued, and the energy press has contacted Maurer and Anadarko for progress updates and information about the project. A number articles have appeared in Pe*troleum New Alaska, Hart's E&P, World Oil,* and others.

PHASE II

The overall objective of Phase II is to test exploitation techniques developed in Phase I by drilling/coring and completing one or more wells, and then performing a comprehensive battery of well tests and logs. Next, the well will be monitored to develop long-term production options. Tasks to accomplish these objectives are described below.

The current schedule for Phase II is shown in **Figure 6**.

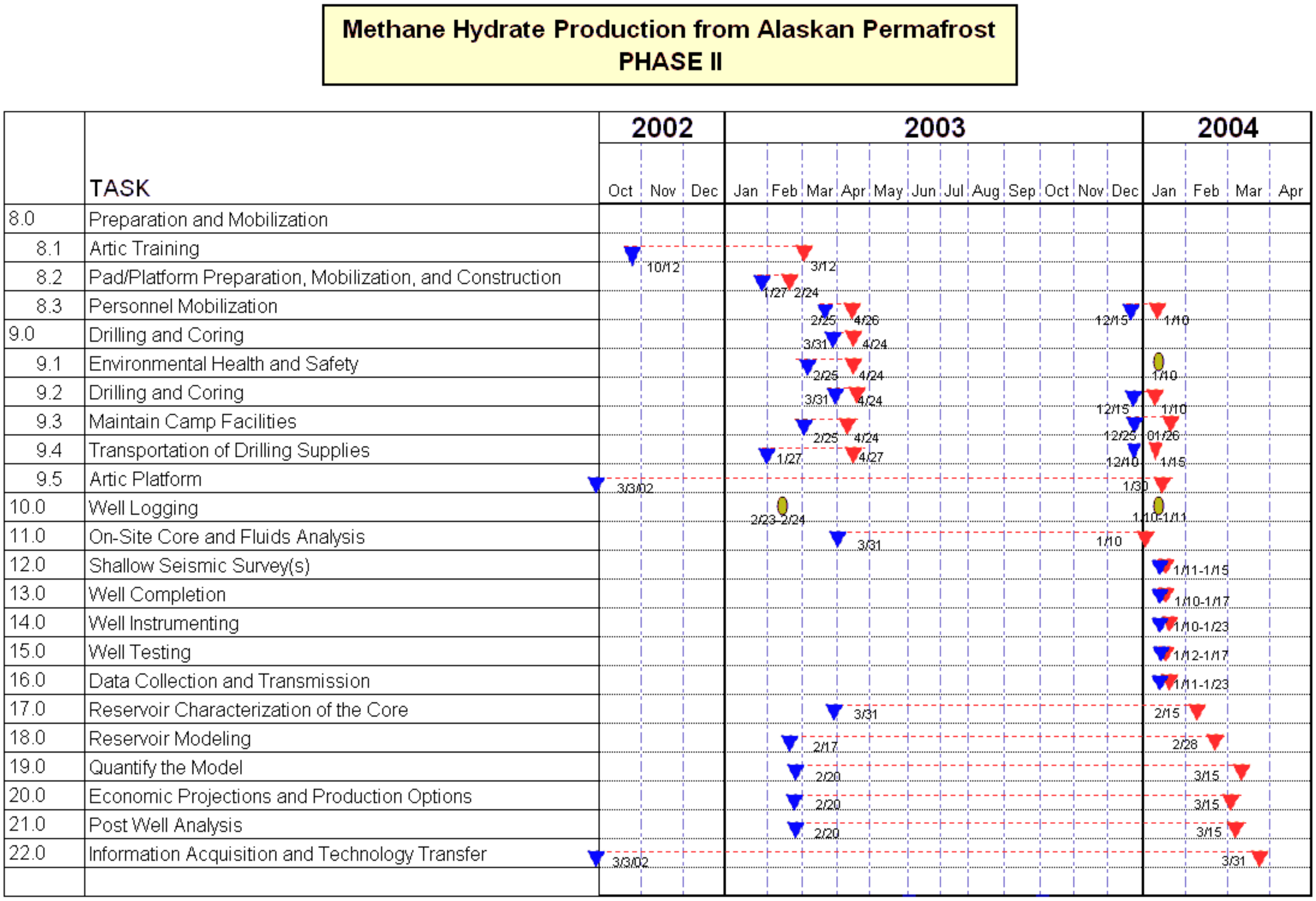


Figure 6. Phase II Project Schedule

Task 8.0 – Preparation and Mobilization

Subtask 8.1 Arctic Training

The required training has been completed for all personnel who will be working on the North Slope overnight in support of this project. Training courses included: First Aid, Respiratory, FIT Test, H_2S Training, NSTC Training, Hazcom/Hazwoper, PPE, Alaska Safety Handbook, Arctic Survival, Bear Awareness, NPRA Training, and Fire Extinguisher Training.

Subtask 8.2 Pad/Platform Preparation, Mobilization, and Construction

Permits have been issued, and the arctic platform was installed at the well location in February. The recipient has mobilized the drill platform equipment to the well location, using an existing gravel road and a staging area at the end of the road.

Subtask 8.3 Personnel Mobilization

The recipient shall transport all project personnel to and from the well site. This task shall include transport of camp crew, catering staff, maintenance crew, rig crew, lab crew, logging crew, cementing crew, mud crew, and supervisory personnel.

Task 9.0 – Drilling and Coring

The recipient has winterized the drill rig and mobilized it to Deadhorse and then to the well location. The recipient shall drill and core one or more wells from the arctic platform.

Subtask 9.1 Environmental Health and Safety

The recipient shall monitor and respond to environmental health and safety concerns, including monitoring and manifesting waste, in order to ensure compliance with regulations specified in permits.

Subtask 9.2 Drilling and Coring

The recipient shall drill and core one or more wells from the arctic platform constructed in Subtask 8.2. The recipient shall use the Noble Engineering and Development Drill Smart System to allow engineers to monitor and view drilling operations live from Houston.

Subtask 9.3 Maintain Camp Facilities

The recipient shall provide camp facilities to house and feed the crews rotating on a 12/12 shift schedule.

Subtask 9.4 Transportation of Drilling Supplies

The recipient shall transport by trucks and rolligons personnel, equipment, and supplies used in the drilling operations, including drilling fluids and drilling mud.

Subtask 9.5 Arctic Platform

The Anadarko Arctic Platform was constructed and tested in Houston, Texas. The structure is made of lightweight aluminum. It was mobilized to the base camp in January 2003, and inspected prior to mobilization to the well location in February (**Figure 7**). The legs were tested and put on location as soon as the freeze period began in January. A video of the transportation and construction was provided to the DOE. Legs were installed into the tundra permafrost and frozen into place. The platform can be mobilized by either helicopter and/or Rolligon from the base camp and assembled at the well location. Environmental monitoring equipment was also installed.

Figure 7. Arctic Platform at Hot Ice #1

The platform drilling area is 100 x 100 ft, and the base camp is 62.5 x 50 ft on an adjacent platform. The rig, equipment and base camp were installed on the platform by Rolligon and two cranes. After completion of drilling and completion operations, some of the equipment will be demobilized, with the remainder staying until well testing has been completed. The entire platform will be demobilized to Dead Horse. The platform will be thoroughly inspected by a third party and a post-analysis study conducted with recommendations on future operations. A thorough report will be provided after completion of this subtask.

Task 10.0 – Well Logging

The recipient shall run a suite of logs in the well(s) to characterize gas hydrate-bearing intervals, including the following: 1) electrical resistivity (dual induction), 2) spontaneous potential, 3) caliper, 4) acoustic transit-time, 5) neutron porosity, 6) density, and 7) nuclear magnetic resonance. Core data will be used to calibrate and quantify log information.

Task 11.0 – On-Site Core and Fluids Analysis

The recipient shall analyze core and fluids using a specially constructed mobile core laboratory, staffed by trained laboratory technicians. Core will be received in the cold module, where it will be photographed and assessed for the presence of hydrate. One-inch plugs will be removed from the core, and these plugs will be measured for porosity, permeability, compressional and shear wave velocity, resistivity, thermal conductivity, and NMR with specialized equipment specifically designed for making these hydrate core measurements, including a Schlumberger CMR tool. All of these measurements will be made under controlled pressure and temperature. Hydrate dissociation shall be monitored. Laboratory technicians will assist in preparing core for additional testing at other locations. Results of core and fluids handling procedures will be incorporated into the DOE-funded Westport Hydrate Core Handling Manual. The results of the analysis will be incorporated in Tasks 17, 18, 19 and 20.

Regarding the use of the LBNL CT (**Figure 8**) on site:

1. We are partitioning one end of a 20-ft Conex with a separate door to the outside for the X-ray room

2. There will be heater located in the room or an electrical outlet to add a portable heater

3. The x-ray room is adjacent to the station where the core will be cut to 3-ft lengths

4. Core sections will then be taken outside and then into the x-ray room

5. The x-ray machine can be started in a temperature-controlled environment

6. During shipment, the machine will be subjected to ambient temperatures as low as -40°F, (unless special measures are taken)

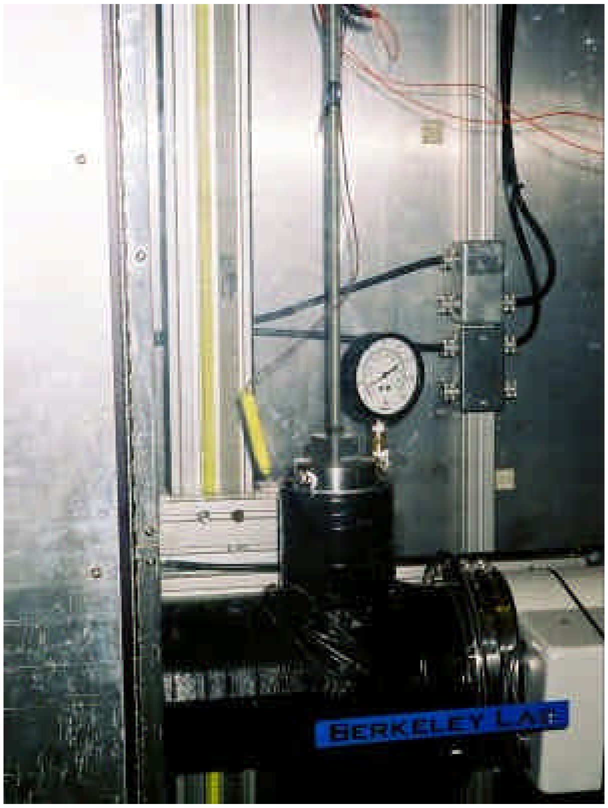


Figure 8. LBNL CT Scanner

The x-ray scanner is certified to be "cabinet safe." This means that any personnel can be near it for normal operation, and the user does not need to be fitted with a dosimeter. Only a certified "system maintainer" can use tools to perform maintenance and has the ability to modify or override interlock safety features. This authority is granted from our EH&S department, and Victor will be the system maintainer. He will bring his own badge.

Regarding operation: the machine will need to be "tuned" to the samples that are collected. This means that adjustments must be made to both x-ray voltage and current depending on the density and composition of the samples. There could also be adjustments to the camera behind the image intensifier. It is hard to predict how often and when this task will need to be performed. Since we will be performing dual-energy scanning, both our hard and soft x-ray energies will need to be periodically readjusted depending on the collected core density and composition.

LBNL modified the machine so that it will hold a 3-ft piece of core. Four-ft long core holders were constructed since the extra space at the top of the core holder will be empty, preventing concern about core length. The quick scan will be performed in about two to three minutes from the time the sample in the sample holder is placed in the x-ray unit, to when it can be removed from the x-ray unit. A more detailed full 3-D CT characterization will take about 12 minutes for the entire 3-ft length. A shorter interval (i.e., 4 inches) can be scanned in full 3-D mode in about 2 minutes. We will have three to five core holders so that one can be loaded, while another one is being cleaned or prepped and a third can be in the scanner.

Task 12.0 – Shallow Seismic Survey(s)

After the well has been logged, a 3D vertical seismic profile (VSP) will be acquired to calibrate the shallow geologic section with seismic data and to investigate techniques to better resolve lateral subsurface variations of hydrate-bearing strata. Paulsson Geophysical Services, Inc. will deploy their 80 level 3C clamped borehole seismic receiver array in the wellbore to record samples every 25 feet. The surface vibrators will successively occupy 800 different offset positions arranged around the wellbore. This technique will generate a 3D image of the subsurface. Correlations of these seismic data with cores, logging, and other well data will be generated.

Task 13.0 – Well Completion

After the seismic data have been collected, the recipient shall complete the well. The completion method will be determined based on the results of drilling, coring, and logging. The base case is to produce one well completed in a single hydrate interval below the permafrost using tubing conveyed perforating guns and permanent downhole pressure gauges. The well shall be perforated in the hydrate interval after cementing 4-1/2 inch casing. The water and gas shall be produced into the production tubing after the hydrostatic pressure is reduced by swabbing. The well will be shut in downhole with a slickline plug to reduce wellbore storage volume. The well shall be equipped with multiple electronic BHP/temperature memory gauges near the perforations. A heat strip will be attached to the testing string to prevent fresh produced water from refreezing across from the permafrost when the well is shut in.

BHP/temperature gauges and heater cable shall be run into the well on 2-3/8 inch NU production tubing. Production facilities consisting of a two-phase vertical separator with gas and water measurement in a winterized enclosure will be hooked up. After testing, the well will be plugged and abandoned.

Task 14.0 – Well Instrumenting

The recipient shall equip the well(s) with downhole pressure and temperature transducers as part of the completion. This will allow the well(s) to be monitored during testing, and it will provide extended monitoring capabilities. It is anticipated that the well will be plugged and abandoned before tundra closure. At this time we do not have regulatory approval to work on the well after tundra closure. With the low anticipated production rates and the relatively short production time, there should not be a need for an extended pressure monitoring program.

Task 15.0 – Well Testing

The recipient shall commence well testing shortly after the well(s) has been perforated and the tubing run in the well(s). The well(s) will initially be produced with a large draw down to determine the productivity of a hydrate zone without thermal stimulation. The well(s) will be produced for a short time to determine if a stabilized rate is obtained. It will then be shut in and the bottomhole pressure recorded. The length of time the well(s) will be produced and shut in has not yet been determined. The total producing time will be approximately 5 days. Water and gas samples will be collected to determine composition.

Task 16.0 – Data Collection and Transmission

The recipient shall perform lab work and collect data on fluids captured during the well testing. The recipient shall also collect and transmit extended monitoring information.

Task 17.0 – Reservoir Characterization of the Core

The recipient shall characterize the hydrate reservoir, based on analyses of fluids, geology, engineering, logs, geophysics, and rock physics. All these data will be included in a well simulator. The recipient shall determine the percentage of gas contained in the hydrate zone that can be recovered from the reservoir, and the potential production rates. Core studies will be conducted to accurately predict reservoir producibility potential.

Task 18.0 – Reservoir Modeling

The recipient shall use information developed in reservoir characterization efforts to quantify Lawrence Berkeley National Laboratory's hydrate simulator. LBL's advanced simulator system is based on EOSHYDR2, a new module for the TOUGH2 general-purpose simulator for multi-component, multiphase fluid and heat flow and transport in the subsurface environment. Reservoir simulation during this phase of the project will focus on considering production schemes, both short and long term, for hydrate production on the North Slope based on all the reservoir characterization data obtained. Depressurization, injection and thermal methods are some of the production processes to be considered with the simulation.

Task 19.0 – Quantify the Model

This task will parallel Tasks 17 and 18. The reservoir model used will need to be continuously refined as well test data are acquired. This effort is an ongoing task required for making projections. Models will be enhanced iteratively to incorporate dynamic production data during the well test period.

Task 20.0 – Economic Projections and Production Options

After all model results are received, the recipient shall assess economic projections and production options. The recipient shall present the results of the program to the Advisory Board and DOE. Information from other gas-hydrate projects shall be reviewed and included in our recommendations. Model-based estimates and production options will then be developed. If it is determined that a significant volume of gas production from hydrates is technically possible, an economic analysis will be conducted.

Task 21.0 – Post Well Analysis

This task is designed for planning to conduct operations including an extended well production test in 2004 on another area of the North Slope of Alaska. A report and budget for an additional well and an extended well test will be produced based on the information generated from the Phase II activities (including lessons learned). It will be determined if an additional well and/or extended production test is warranted, and recommendations will be presented to the DOE in sufficient time for FY 2004 budget planning. We anticipate the additional well will be drilled in another lease area/region of Alaska. The production test plan will help determine the producibility of hydrate deposits. These plans will be valuable for future hydrate operations, even if this project is not extended into Phase III.

Task 22.0 – Information Acquisition and Technology Transfer

The recipient shall communicate and exchange information with experts in the field of hydrate well drilling, coring, and testing, including Advisory Board members, to stay abreast of the latest technology and preferred methodologies. The recipient shall also document results of the field tests and transfer this technology to the industry.

Subtask 22.1 Information Acquisition

The recipient shall identify and network with other experts in the field of hydrate well drilling, coring, testing, and analysis to gain insights into the latest methodologies and technologies. The recipient shall follow the latest developments related to hydrate wells by meeting with experts in the scientific and drilling communities.

Subtask 22.2 Technology Transfer

The recipient shall document project results and transfer the new information and technology to the industry, via web site postings, meetings, workshops, and at least one technical paper. The recipient shall also use the NED Smart Drill system to allow well activities to be viewed by scientists, engineers, and DOE project managers who are not present at the well site.

DELIVERABLES

The periodic, topical, and final reports shall be submitted in accordance with the attached Reporting Requirements Checklist and the instructions accompanying the checklist. In addition, the Recipient shall submit the following:

Phase I

1. Digital Map of all well locations in and adjacent to project area (Task 2.1)
2. Well log correlation sections showing lithologic and stratigraphic units that fall within the gas hydrate stability zone in and adjacent to the project area (Task 2.1)
3. Seismic maps and sections showing extent of stratigraphic and lithologic units that fall within the gas hydrate stability zone in and adjacent to the project lease area (Task 2.2)
4. Reservoir modeling report for proposed site (Task 3.0)
5. Well Data for individual control wells used for site selection (Tasks 2.1 & 4.1)
6. Site Selection Plan (Task 4.1)
7. Testing and analytical procedures report (Task 5.0)
8. Well plan(s) (Task 6.0)

Phase II

1. Drilling and Coring Report (Task 9.2)

2. Well Logging Report (Task 10.0)

3. Core and Fluid Analysis Report (Task 11.0)

4. Seismic Survey Report (Task 12.0)

5. Well Completion Report (Task 13.0)

6. Well Testing Report (Task 15.0)

7. Hydrate Reservoir Characterization and Modeling Report (Tasks 17, 18, &19)

8. Economic Projections (if production volumes dictate) and a Production Options Report (Task 20.0)

9. Plan for Future Hydrate Well on the North Slope (Task 21.0)

10. Technical Publications Summarizing Project Findings (All Tasks)

11. Final Report Summarizing Project Findings (All Tasks)

In addition to the required reports, the recipient shall submit informal status reports directly to the COR. These are preferred monthly with short descriptions of successes, problems, advances or other general project status information. The report should not exceed one page in length and shall be submitted via e-mail.

The Contractor shall also provide the following to DOE: a copy of all non-proprietary data, models, protocols, maps and other information generated under the cooperative agreement, when requested by DOE, in a format mutually agreed upon by DOE and the participant.

5. Conclusions

Operations on the Hot Ice #1 Hydrate Well are currently suspended pending the return of cold weather. Anadarko is committed to resume coring operations in the fourth quarter of 2003, prior to the opening of the conventional operations season. Casing was set just above the West Sak formation and a sand accumulation at the top of the West Sak should provide a good chance to encounter hydrates. After operations commence, the hydrate stability interval will be cored to approximately 2200-2400 feet (670-732 meters) deep. After total depth is reached and the well ID logged, depending on the amount of hydrates encountered, a final completion program will be formulated.

The complete set of core, well log, production and downhole pressure and temperature data will be made available for use in evaluating the hydrate reservoir's quality and to determine the potential for production from arctic hydrate intervals. The data will be incorporated into hydrate reservoir models to test possible scenarios for producing methane from hydrates in similar settings.

DOE NETL has also established a special web page for references to their support of gas-hydrate development. At their site (http://www.netl.doe.gov/scng/hydrate/) are posted updates describing the Hot Ice project as well as the latest version of "Fire in the Ice," the National Energy Technology Laboratory Methane Hydrate Newsletter. The most recent version of the newsletter is Spring 2003.

6. References

No references are cited in the body of this Quarterly Report.

Appendix A: Hot Ice #1 Site/Rig Photos

Figure A-1. Hot Ice Well #2 Site

Figure A-2. Base Camp

Figure A-3. Setting the First Platform Module

Figure A-4. Assembling the Platform

Figure A-5. Complete Camp Ready for Drilling

Figure A-6. Team Members on the Rig Floor

Appendix B: Gas Hydrate Project Production Testing; North Slope, Alaska

Testing Objective

Naturally occurring hydrate formations are present as a solid in the hydrate-stability zone. Hydrate will remain a solid until formation conditions are moved outside of the hydrate-stability region. The hydrate-stability region is a function of pressure, temperature and composition of the gas and fluid in the pore space. The main purpose of the production test is to monitor production response from depressurizing a hydrate interval over a short period. It is not anticipated that production from the hydrate interval during the test would be economic even if there were a gas pipeline available and the gas could be sold. The main objective is to collect information on depressurization to calibrate the hydrate production simulator. The calibrated simulator can then be used to determine the most economical method of trying to commercially produce hydrates. It is anticipated that depressurization of the hydrate interval by depleting a free gas interval will be the most likely way to generate commercial quantities of gas from a hydrate interval. The testing objective is to gather information so that reservoir simulators in the future will be able to accurately predict hydrate dissociation that results from depressurization.

Completion Challenges

The completion of this well (**Figure B-1**) was designed to try to address all of issues that have been identified with producing hydrates at this location. Based on the rig capacity, the largest production casing that can be used below the permafrost has an outside diameter of 4.5 inches. This will have a drift diameter of approximately 4 inches. The location will not be accessible by ice roads during production testing. All equipment will be transported by rolligon or helicopter. As a result, size and weight of the equipment needs to be minimized. Completion and testing equipment need to be simple and require minimum support. With environmental regulations and cost constraints, the base plan will conclude testing before tundra closure occurs. The current plan is not to incorporate artificial lift in the base plan. There is also potential for formation sand production. Freeze protection has to be incorporated into the completion design. The fact that the well produces fresh water and predominately methane creates the possibility of forming hydrates or ice in both the tubing and tubing/casing annulus. The potential for having hydrate or freezing problems is greatest during shut-in periods.

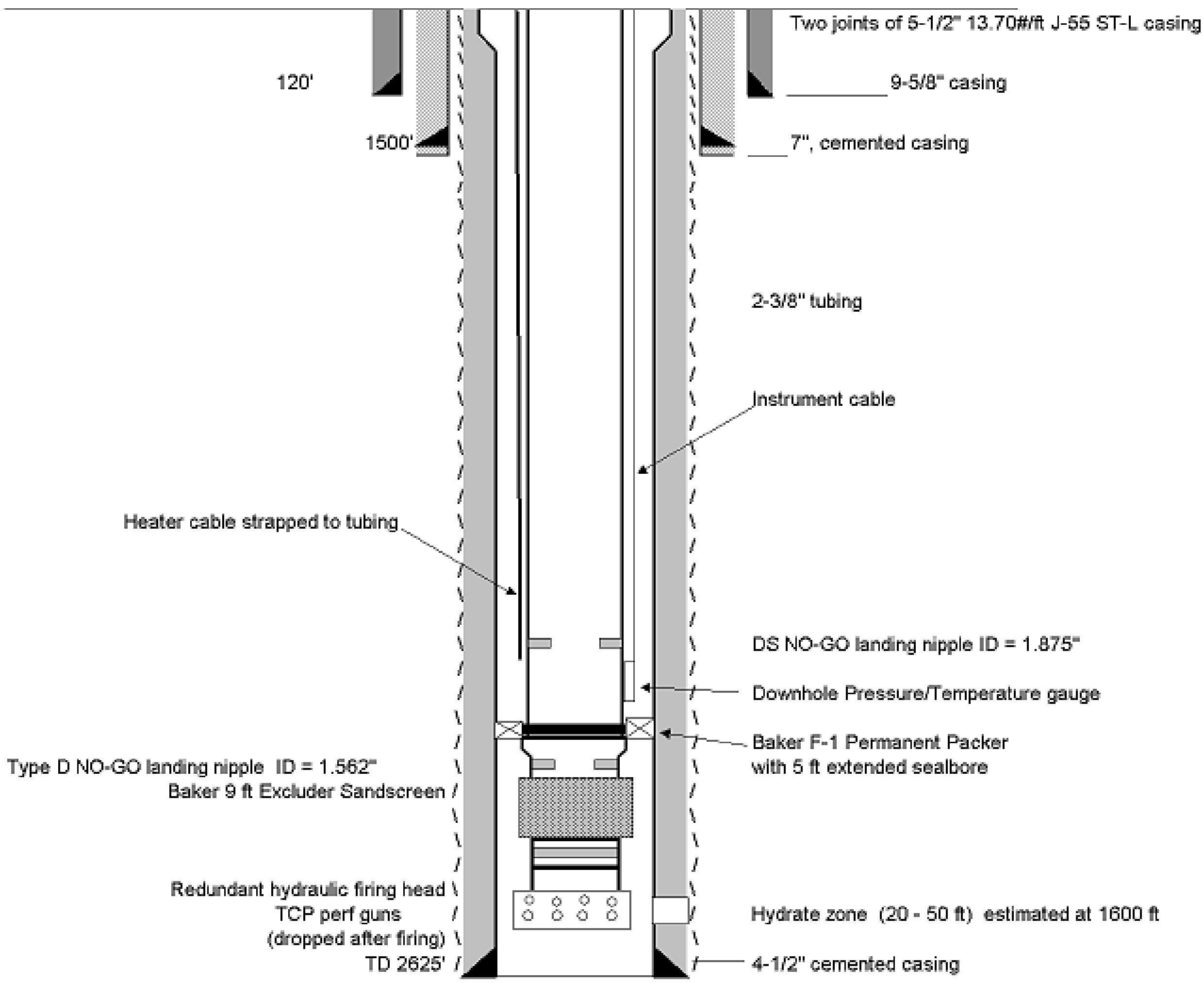


Figure B-1. Hot Ice #1 Completion

Completion Base Plan

There will be a number of uncertainties until we pull core from the well. We plan to perforate one hydrate interval after cementing 4-1/2 inch casing. The base case is to produce one well completed in a single hydrate interval using a tubing string, packer and permanent downhole pressure/temperature gauges. Water and gas will be produced into the tubing string. We will have the capability to swab the well to reduce bottomhole producing pressure. The well will be set up so that it can be shut in downhole by setting a plug in a profile to reduce wellbore storage volume. The well will be equipped with two electronic bottomhole pressure gauges and one temperature gauge near the perforations. A heat strip will be attached to the tubing string to prevent fresh produced water from refreezing across from permafrost when the well is shut in.

The base completion plan is to perforate one interval that is located at a depth with a reservoir temperature greater than 32°F. After the completion is run, production facilities consisting of a two-phase vertical separator with gas and water measurement in winterized enclosures will be hooked up.

A heater cable will be used to keep the water in the production tubing from freezing. It is anticipated that produced water will have a low salinity. The undisturbed surface temperature is approximately 12°F. As a result, there is a high probability that there will be a problem with water freezing or hydrate formation inside the tubing, if heat is not added. The heater cable is basically a flat ESP cable that is shorted above the packer. Electrical current flowing through the cable results in the generation of heat. The majority of the heat generated is transferred to the production tubing. Modeling results predicted that the heater cable would keep the temperature of the fluid inside the tubing above 50°F.

A heater cable should eliminate problems with water freezing, but adds other completion challenges. Using a heater cable requires the use of wellhead penetration. There is not enough room in a standard wellhead for 4-1/2 inch casing to have a high amperage penetration. To solve this problem, two additional casing spools will be used to allow the electrical penetrator. The top two joints of casing will be 5-1/2 inch so that there is enough room for the splices and the pigtail connection. With the heater cable and standard 2-3/8 inch EUE tubing, there is very little clearance inside of the 4-1/2 inch casing. The weight of 4-1/2 inch was reduced to 9.5 pounds per foot to give the largest possible internal diameter. This results in a clearance of slightly more than 0.25 in. between the heater cable over the coupling and drift of the 4-1/2 inch casing. This is especially tight since Range 1 tubulars (15-24 ft/joint) will be utilized for this project since a continuous coring rig is being used to run the completion equipment. 2-3/8 inch NU (10rd) tubing will be used in place of 2-3/8 inch EUE (8rd) tubing to increase the clearance by approximately 0.20 inch at each connection.

The well will be set up so that bottomhole pressure and temperature measurements can be made from the surface. Because of the large cost to come back and plug the well in an isolated Arctic environment, it is planned to plug the well at the end of the production test. This will also minimize the need to mobilize equipment at a later time to the well and reduce environmental impact.

Testing Base Plan

The well will be swabbed down to initiate flow. Produced gas will be vented or flared after being measured. Produced water will be pumped into a holding tank and later hauled to disposal using a rolligon at the end of the test. The well will initially be produced to determine productivity of a hydrate zone with only depressurization. The well will be produced for a short time to determine if a stabilized rate is obtained. The well will then be shut in. If necessary, a plug can be set in a profile to minimize the wellbore storage during the build-up test. The total test time will be approximately 5 days. A water and gas sample will be collected.

The testing plan outlined in this document is the current base plan. Simulation modeling is currently being performed that will estimate production for different reservoir conditions. Production and shut-in periods may have to be altered based on the actual reservoir parameters observed and the amount of time that is available before tundra closure.

Contingencies

As mentioned previously, there are a number of contingencies that have been considered in the completion design. At this time, we are not sure what production rate the well will be capable of producing as a result of uncertainty about reservoir parameters. There is also a contingency related to sand control. It is currently assumed that the formation is not completely unconsolidated. The base plan is to use a sand screen below the packer. This should be sufficient as long as low production rates are encountered. A contingency of using expandable sand screens was investigated. An expandable sand screen will be extremely difficult to install at this shallow depth. It would require that special 20-foot drill collars be manufactured to have enough setdown weight to expand the sand screen. Using an expandable screen would also require that the zone be perforated prior to running tubing.

Regulatory permit approvals for gas/emissions and fluids disposal will also be factored into contingency plans.

Longer Term Testing Option

The current Phase 2 proposal incorporates funding for a testing period of about 5 days without artificial-lift equipment. A scenario was also developed to produce the hydrate interval for an extended time period. The longer-term test is based on one well completed in a single hydrate interval with a progressive cavity pump set below the perforations. The completion plan would include a fiber-optic line embedded inside the instrument cable for the downhole gauge. The fiber-optic cable will give temperature every meter along the wellbore from the surface to below the hydrate region.

The base completion plan is to perforate one interval that is located at a depth with a reservoir temperature of greater than 32°F. The torque anchor, sand screen, progressive cavity pump, bottomhole pressure/temperature gauges and heater cable could be run into the well on the production tubing. The rotor for the progressive cavity pump will be run into the well on 7/8-inch steel sucker rods with rod guides. The rotor will be spaced out and the drivehead assembled. The progressive cavity pump has the advantage that the drive head has a small footprint that can be enclosed to prevent the wellhead and lines from freezing. At this point, production facilities consisting of a two-phase vertical separator with gas and water measurement in winterized enclosures will be hooked up.

It is planned to produce water up the tubing and gas up the annulus. The well will be equipped with a BHP/Temp gauge near the perforations. A heat strip will be attached to the production tubing to prevent fresh produced water from refreezing across from the permafrost when the well is shut in. Produced gas will be vented or flared. Produced water will be pumped into a holding tank and later hauled to disposal using a rolligon. A complete automation system could be installed to monitor the wellhead and separator pressure and temperature, water and gas production and tank levels. The automation system would also allow pumping and ESD equipment to be operated remotely.

The well would initially be produced with a progressive cavity pump to determine productivity of a hydrate well without thermal stimulation. The bottomhole pressure gauge will interface with control equipment for the progressive cavity pump to control the variable frequency drive and turn equipment off when the fluid level is below the perforations. The well will be produced for a short time to determine if a stabilized rate is obtained. The well will then be shut in and bottomhole pressure observed. At the end of this build-up period, the progressive cavity pump will be restarted and production rate compared to the rate prior to shut-in. With the fluid level near the perforations, hot water will be pumped down the production tubing/casing annulus into the perforated interval. The well will be shut in for a short time to allow heat to be transferred to the hydrate interval. The pump will be set below the perforations to prevent elastomers in the progressive cavity pump stator from being exposed to hot fluid injected down the annulus. The well will then be returned to production, and bottomhole pressure will be monitored during the production test.

It is planned to repeat the hot water injection, production and shut-in sequence. The number of cycles will depend on total test time and production response from the hot water injection. We will attempt to use the same hot water volume, producing time and shut-in time so that results of different production cycles can be compared. Length of production and shut-in times may need to be adjusted based on production and build-up results. Water and gas samples would be collected during each production cycle to determine if composition is changing with time.

At this time, we are still trying to determine if it is possible to obtain regulatory approval to perform some extended production testing without anyone on location. Personnel would need to be at the well during initial start-up, while pumping hot water and start-ups after extended shutdowns. To minimize logistics costs associated with housing people at a remote arctic location, we would like to have someone monitor the well and facility automation equipment remotely in Deadhorse, Alaska. People monitoring the well information would have the ability to shut down the pumping equipment and shut in the well if there was a problem. Personnel could be sent out periodically on helicopter or rolligon to monitor or repair equipment at the location. It is possible that we will need to have people located at the well site the entire time the well is being produced.

The extended producing time would give information about long-term production characteristics of hydrates. The long-term test would provide data about effects of injecting multiple hot fluids into the hydrate interval. This would result in a more realistic simulator that could be used to determine production performance of different production scenarios (huff and puff, steam injection, depressurization, etc.).

We have not been able to obtain reservoir simulation results at this time. Based on several papers that have been published, it is anticipated that production rate will be extremely low.

The proposed five-day test using swabbing will provide information used to calibrate the reservoir simulator. The swabbing configuration without the addition of heat will provide a situation that is most similar to the depressurization of a hydrate interval that results from depleting a down-dip gas zone.

Appendix C: Interim Report on Hot Ice #1 Coring, Core Analysis, and Logging Program

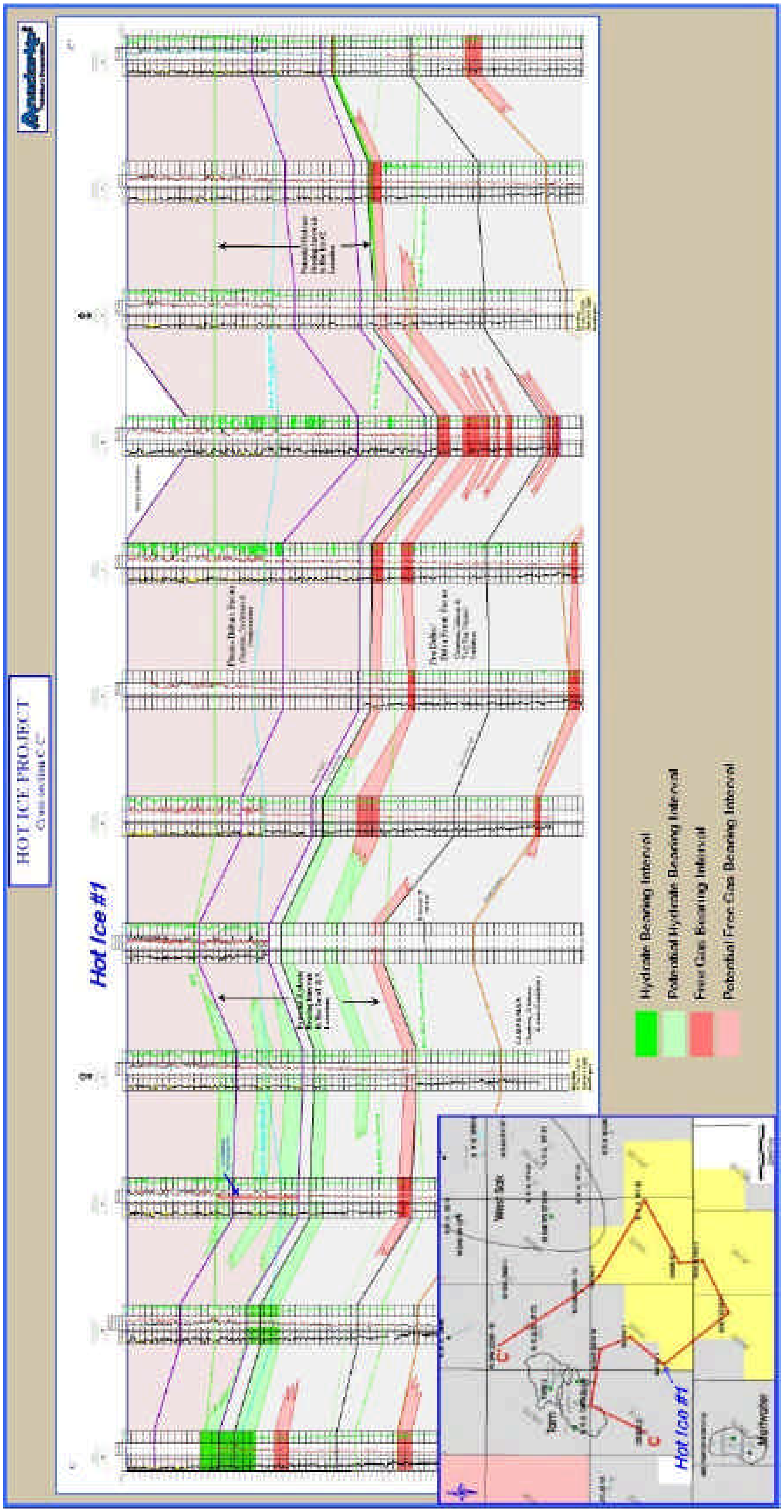
Richard Sigal and Steve Runyon
Anadarko Petroleum Corporation

Log data recorded to date in the Hot Ice #1 well (current total depth of 1403 ft) were compared to data from 11 other nearby (offset) wells. A reduced-size version of the cross-section log is shown on the next page. A larger version of the same log is attached to this report in **Appendix H**.

A well log for the Hot Ice #1 is herein submitted to the COR (in **Appendix G** and on CD). This log also contains a geologic and stratigraphic description of the well.

During the 2003 winter drilling season on Alaska's North Slope, Anadarko acquired continuous core from 107 ft KB (107 ft MSL) to 1400 ft KB (-1186 ft MSL) at the Hot Ice #1 location. A wide range of measurements on the whole core and core plugs were made on site. After the onset of warmer weather, coring was suspended and the well cased after penetration through the base of permafrost. The well bottom is located in a thick shale zone that separates the Ugnu formation from the West Sac. The well was logged by Schlumberger from 107 ft to 1300 ft. The logging suite consisted of gamma, neutron, density, dipole sonic, induction resistivity, and NMR logs.

Ten-foot lengths of core were acquired using a modified continuous-coring mining system. About 95% of the total core was recovered. Every effort was taken to keep the core frozen. The mud system was designed to maintain mud temperature as close to 25°F as possible. The 10-ft sections of core were cut into three 40-inch sections for further analysis in an area kept well below freezing by the ambient outside temperature. The 40-inch sections of core were processed in the continuous lab module, which was also kept cold by the outside temperature. Here the core was photographed, a core gamma recorded, and a geological description recorded. Also, an NMR measurement was made on a 6-inch section from each 40-inch section using a Schlumberger CMR tool adapted for core measurement and provided by Schlumberger. The continuous core module also contained equipment for preparing 1-inch core plugs that were used for further core characterization. After being processed in the continuous module, all cores were stored in a freezer container. The core (minus the core plugs) has been donated to Shirish Patil and his group at the University of Alaska Fairbanks.


HOT ICE PROJECT
Hot Ice #1
Hydrate Bearing Interval
Potential Hydrate Bearing Interval
Free Gas Bearing Interval
Potential Free Gas Bearing Interval
West Sak
Hot Ice #1
C
C'

Core sections identified as sands were plugged at locations recommended by the geologists. The locations were chosen to sample the complete range of observed sandstone rock types. Separately, Charles Barker of the USGS (who was on site) took coal samples for analysis. Craig R. Woolard of the University of Alaska later took water samples.

While the 1-inch plugs were frozen, shear and compressional velocities, resistivity, thermal conductivity, and NMR T2 decay spectra were measured. After cleaning and drying, porosity, permeability, and grain density were measured at three confining pressures. The cleaned and dried plugs also had the frozen measurements repeated.

Due to various drilling problems, the borehole was badly washed out in some places, and only within gauge in a few places. This adversely affected the logging program. The gamma, density and neutron tools seemed to record valid data, but further analysis will be needed to quantify the effects on other tools.

This interim report (see next page) contains an analysis of the geological observations made on the core, and on the measured porosity and permeability data. Core observations confirm the general geological cross section prepared before drilling. Also included in the report in borehole log format are the core description, core gamma, porosity and permeability data, and field copies of all the logs except the CMR. Velocity, resistivity, NMR, and thermal conductivity measurements will require more analysis.

The primary goal of the coring operation was to core hydrate-filled sediments. Judging from the hydrate accumulations to the west of the Hot Ice #1 location, hydrates were expected to be found in the vicinity of the base of permafrost. No hydrates were identified in the recovered core. There was evidence of small amounts of gas in the system near the permafrost base. The presence of gas was inferred from gas bubbles appearing to be escaping from the core, and fractures in the clay zones that resemble the effects caused by gas trying to escape from a very tight unconsolidated core. These zones were carefully examined for any trace of hydrates, but if any was present it had all dissociated. It is hypothesized that the thick shale immediately below the base of permafrost may have sealed off the gas in the system from the sands above it. It is expected that the highest probability to core hydrates will be in the sands at the top of the West Sak formation.

Coring for Methane Hydrate in Shallow Sands of the Sagavanirktok Formation North Slope, Alaska – Phase I: Progress and Geologic Description

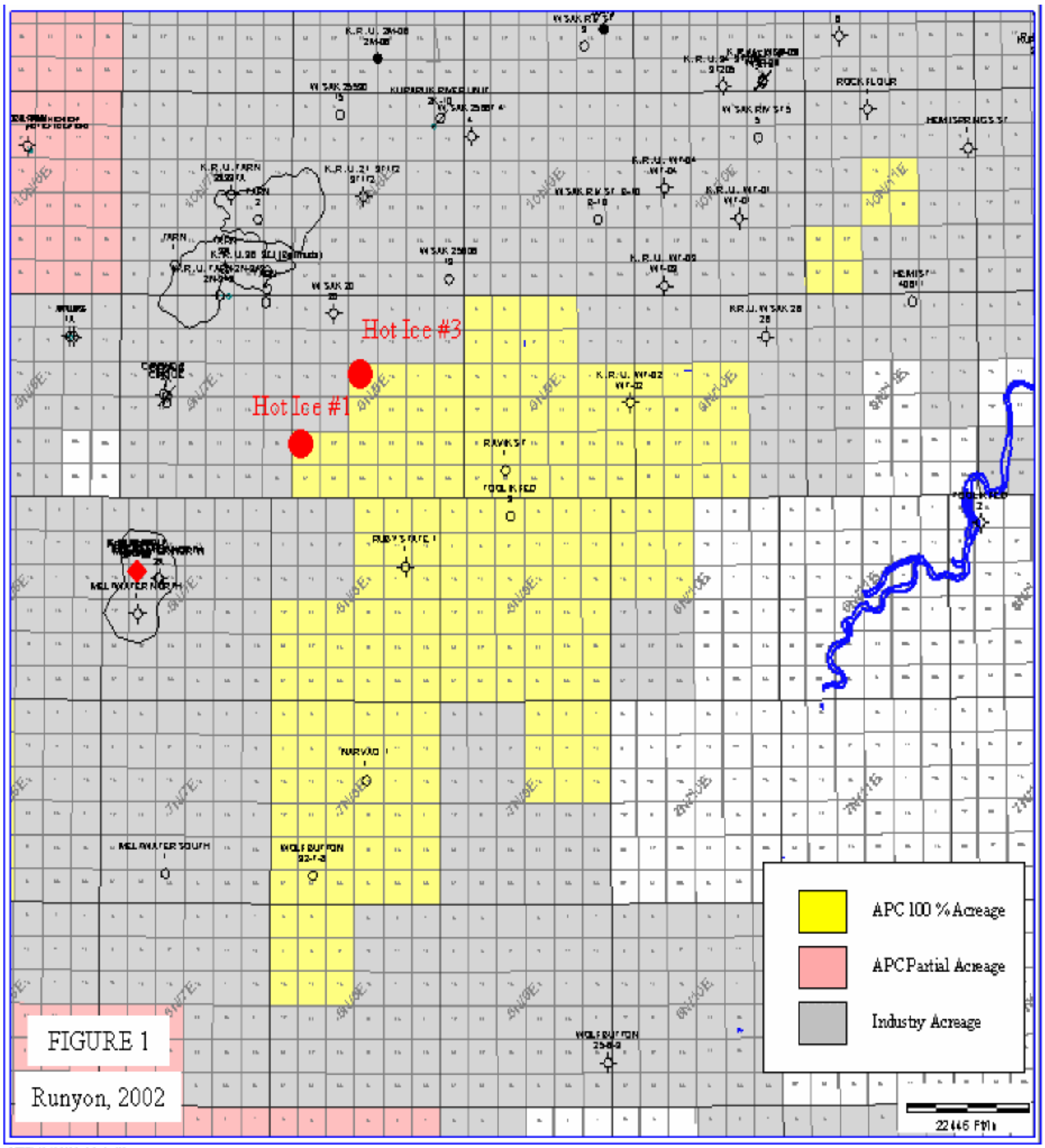
W.J. Ebanks, Jr.[1] and W.D. Zogg[2]

Introduction

Most known subsurface North Slope gas hydrates occur in lower Tertiary sandstones and conglomerates overlying the eastern part of the Kuparuk River oil field and the western part of the Prudhoe Bay oil field (Collett, 1993). On the North Slope, the methane-hydrate stability zone is areally extensive beneath most of the coastal plain province. The presence of methane hydrate has been inferred from numerous North Slope wells on the basis of well log responses calibrated to the response of an interval in a well where gas hydrates were recovered in a core by ARCO and Exxon (Collett, 1993).

Recognizing the potential importance of this untapped source of natural gas, Anadarko Petroleum Corp. and its partners are taking cores of sedimentary deposits in the subsurface of the North Slope that will provide material for experimentation leading to further evaluation of this resource. The location chosen for drilling and coring of a well (named Hot Ice #1) is on acreage leased earlier by Anadarko, about two miles south of the present boundary of Kuparuk River Unit and five miles east of the Meltwater development, in NW/4, Sec. 30-T9N-R8E, Umiat Meridian, on the North Slope of Alaska (**Figure C-1**). This location was chosen to maximize the chance of encountering gas hydrates beneath Anadarko's leases.

The Anadarko Hot Ice #1 well has surface conductor pipe set in permafrost at 107 ft MD. The well was drilled out of this casing on April 1, 2003. Original projected total depth was 2600 ft. Due to delays in project initiation and subsequent early onset of spring thaw conditions on the North Slope, drilling had to be halted on April 13, 2003. The well was cored continuously from 107 ft to a total depth of 1400 ft. Surface casing was set at this depth, and the well was placed in "suspended" status. Coring will be resumed during the next drilling season.



Geology

Geology of the North Slope of Alaska has been the subject of numerous earlier reports (Morgridge and Smith, 1972; Jamieson et al., 1980; Carman and Hardwick, 1983; Molenaar et al., 1986; Werner, 1987; Gryc, 1988; Collett, 1993). The general setting of the location where the Hot Ice #1 well is being drilled is one of surface and near-surface gravels overlying a section of Cenozoic to Upper Cretaceous sedimentary deposits, which dip east-northeastward at a rate of approximately 100 ft per mile (Runyon, 2003). No faulting is known to affect these deposits in this local area.

Ice-bearing permafrost varies somewhat in thickness from well to well, and the base of this interval has been found to occur at measured depths ranging from about 1100 ft to almost 1500 ft in wells closest to Hot Ice #1 (Newsham, 2003). In the Hot Ice #1 well, the base of ice-bearing permafrost has been found at about 1260 ft MD. No methane hydrate has been found within the permafrost zone in this well. Observation of retrieved cores indicates that chilled drilling mud, rapid coring rate, and wireline retrieval contributed (as planned) to maintaining the frozen condition of the sediments from the permafrost interval. It is expected that similarly frozen, gas-hydrate-bearing intervals that may be encountered below the permafrost zone will likewise remain frozen when brought to the surface by using this coring system. This will facilitate recognition, sampling and preservation of these gas hydrates.

Sediments in which gas hydrates occur in this area of the North Slope comprise parts of the Sagavanirktok Formation, a thick succession of Late Cretaceous to Early Tertiary age (Molenaar, 1986; Collett, 1993) that include sandstones, mudstones, conglomerates and coal. This includes the informal units, the Ugnu and West Sak sands (Collett, 1993), which are reservoirs containing heavy oil farther north (Werner, 1987). The Hot Ice #1 well began coring in frozen surface gravels at 107 ft, probably the Gubik Formation. After 7 ft of these gravels were cored, it passed into the Sagavanirktok Formation, but penetrated only as deep as the mudstone between the lower Ugnu sands and the West Sak sands (Werner, 1987; Runyon, 2003). No gas hydrates were encountered during the present phase of the coring operation.

Sediments above 1360 ft in the Hot Ice #1 well, shown in the graphic log (Exhibit 1), were deposited in environments that ranged from fluvial to marginal marine and upper deltaic. Alternations of sandstone, mudstone, conglomerate and coal form sequences that indicate an overall progradation and shallowing of environments of deposition with time. There is considerable vertical variability in these shallow sediments, implying lateral variability of the surface environments in which they were deposited. This variability is common in flood plain and deltaic or other near-shore environments. Although sharp lithologic contacts are not uncommon, there are no obvious unconformities within the sediment sequences cored.

Lithologic Logging

The graphic lithologic log prepared for this report is the primary means of communicating information about composition of the sediments in the cored interval (107-1400 ft). This information provides a context for understanding variations in reservoir properties found during analysis of the cores. A legend on the graphic log indicates the colors and symbol codes used to portray the vertical succession of sediment types encountered in coring. This lithologic log will be complemented by selected photos of whole core and of plugs taken for analysis, as well as measurements of porosity, permeability and other petrophysical properties and displays of curves from downhole wireline logs.

This log was compiled by rapid visual examination of each 10-ft segment of the 3.25”-diameter continuous core shortly after it was brought to the surface. This macroscopic core examination was necessarily brief because of the need to prevent the cores from thawing. Upon reaching the surface, each 10-ft segment was further subdivided into three 40-inch sections and part of the drilling mud scraped from one side. These sections were scanned for natural Gamma Ray radiation to compare with downhole wireline logs, for imaging in infra-red light, for white light photography and for logging by a surface-mounted CMR logging tool. Plugs, 1 inch in diameter, were taken from selected lithologies, and end pieces of some of these were examined microscopically for texture and mineralogy. The 40-inch sections were then placed in transparent plastic tubes, the open ends capped, and the cores stored at sub-freezing temperature. Core recovery through the ice-bearing permafrost interval and to total depth of the first phase of drilling (1400 ft) was excellent – about 95%.

The aspect of core description that has been minimized here is the observation of sedimentary structures. Because core could not be slabbed and cleaned for extended examination, only a quick appraisal of those features that could be seen on the outside of scraped core surfaces was logged. Trace fossils other than root casts were not observed, possibly because of this limitation on the logging methods. Samples were not taken for micropaleontologic analysis, so there is no information of this type to contribute to interpretation of environments of deposition. However, these continuous cores of the shallow formations provide a far more accurate representation of the lithologies drilled and their variability than can be obtained from logs of only cuttings.

Lithologic Description

Subdividing the lithologic section for description is based on recognition of changes in predominant rock types, on gradations in grain size within short intervals, the nature of contacts between rock types, and on correlation to nearby well logs. Sediments are given equivalent rock-names, even though they are mostly unconsolidated except for the ice cement. **Table C-1** summarizes the occurrences of each lithology logged, and **Figure C-2** illustrates with charts the changes in composition encountered in the intervals described below. Photographs of representative sections of core are presented on page C-16 and 17.

114 – 143 ft

Beneath the surface gravels is a thick (29 ft) section of horizontally laminated mudstone, which contains a few silty laminae. This mudstone probably is the uppermost part of the Sagavanirktok Formation in this area. Without the aid of paleontology or palynology, its age and environment of deposition are in doubt. The same may be said for the rest of the cored interval; except that correlation with wireline logs of nearby wells may help in determining approximate age, as well as analogy with sediments in other areas may help interpret environments of deposition.

Table C-1. Lithologies Represented in the Cored Intervals

INTERVAL	Thickness	Conglomerate	Sandstone	Mudstone	Coal	lost core
114'-143'	(ft)	6.20	1.00	28.20	0.00	0.40
	(%)	21.38	3.45	97.24	0.00	1.38
143'-252'	(ft)	1.60	52.00	28.50	27.10	0.00
	(%)	1.47	47.71	26.15	24.86	0.00
252'-446'	(ft)	8.00	142.60	26.80	12.70	3.80
	(%)	4.12	73.51	13.81	6.55	1.96
446'-649'	(ft)	131.85	43.50	26.30	0.15	0.80
	(%)	64.95	21.43	12.96	0.07	0.39
649'-760'	(ft)	13.40	60.20	24.90	5.60	4.30
	(%)	12.07	54.23	22.43	5.05	3.87
760'-951'	(ft)	0.00	67.90	97.80	3.50	21.40
	(%)	0.00	35.55	51.20	1.83	11.20
951'-1187'	(ft)	0.00	67.30	125.10	33.50	9.90
	(%)	0.00	28.52	53.01	14.19	4.19
1187'-1358'	(ft)	0.00	131.70	32.00	0.00	6.90
	(%)	0.00	77.02	18.71	0.00	4.04
1358'-1400'	(ft)	0.00	0.10	39.70	0.10	2.70
	(%)	0.00	0.24	94.52	0.24	6.43
TOTAL	(ft)	161.05	566.30	429.30	82.65	50.20
	(%)	12.46	43.80	33.20	6.39	3.88

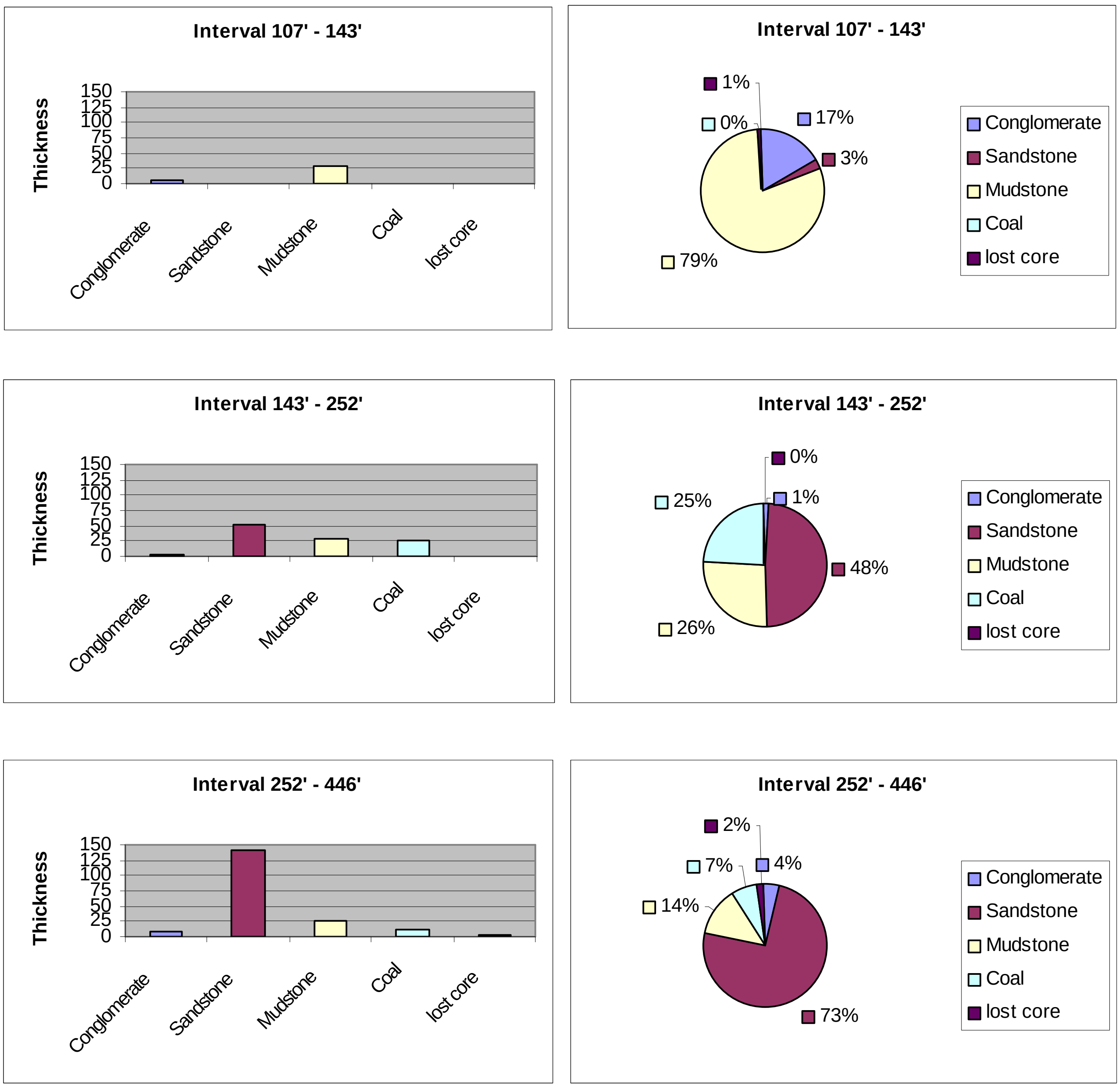
143 – 252 ft

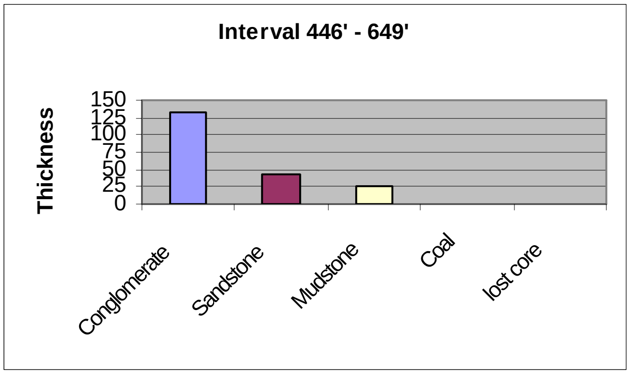
From a depth of 143 ft to 252 ft is an interval of sediments consisting of an overall fining-upward sandstone/mudstone sequence overlain by thick coal. The 49 ft of sandstone at the base is medium to coarse grained and contains carbonaceous fragments and disseminated organic matter probably eroded from a coal below. The sandstone becomes fine to medium grained upward and, at the top, includes scattered pebbles and a few shaly laminae. At the top, the sand is interbedded with a few thin mudstones and is overlain by 18 ft of mudstone that is silty and sandy, becoming carbonaceous just below the overlying coal. The 36 ft of coal is actually four distinct beds separated by thinner, very carbonaceous mudstones. The coal is black, soft and impure lignite containing argillaceous and sandy streaks.

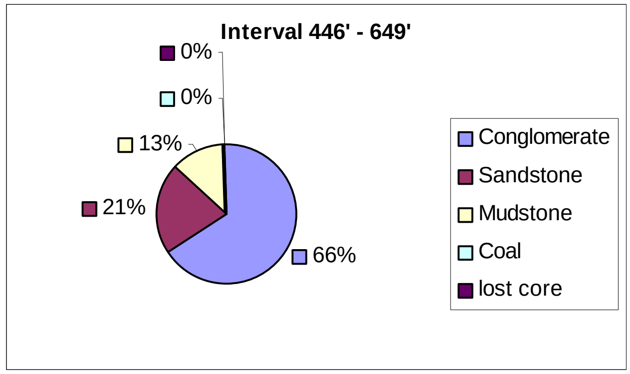
252 – 446 ft

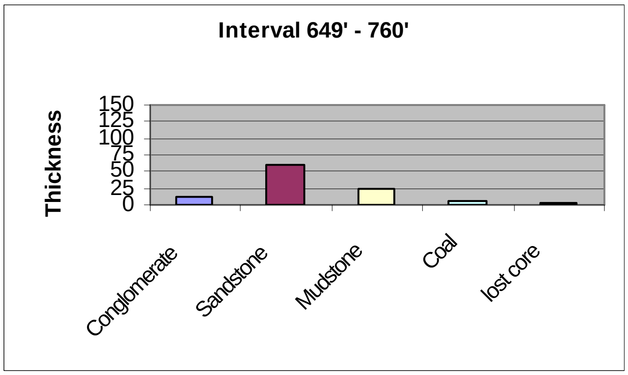
A similar sequence, sandstones below mudstone below thick coal, is present in the interval 252-446 ft. There are significant differences in this interval from that above. At the base are two sequences with a basal conglomerate grading upward into pebbly sandstone, then sandy mudstone. Above this is a thick interval, 110 ft, in which sandstone is the main lithology. This sandstone interval, however, comprises numerous thinner intervals in which medium-to-coarse grained sand grades to fine-to-medium sand. The coarser sandstone has low-angle cross bedding, while the finer grained sands have mostly horizontal bedding. Most of the thin sands grade upward into sandy mudstone. The mudstones commonly have carbonaceous particles on bedding planes. The sandstones at the top of this interval are argillaceous. Those at the base are very carbonaceous.

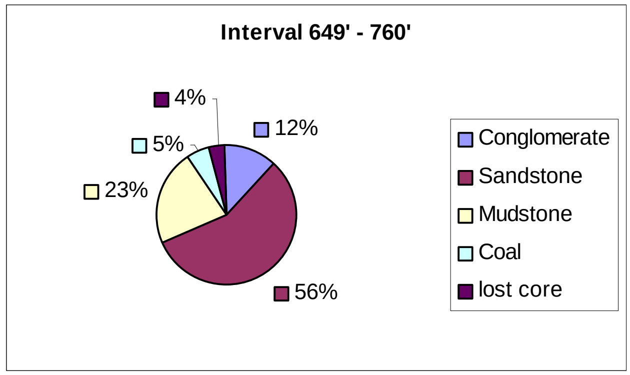
Figure C-2. Changes in Composition by Interval

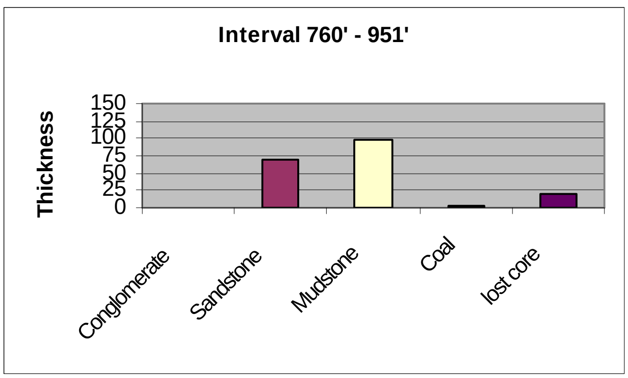


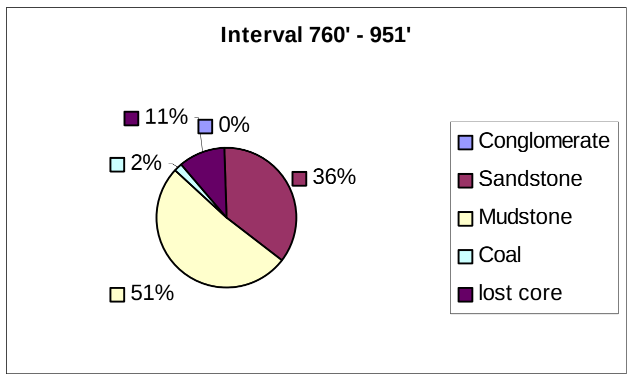

Interval 446' - 649'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core

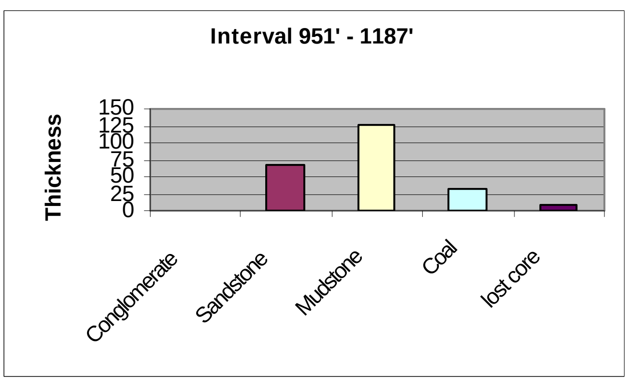

Interval 446' - 649'
0%
0%
13%
21%
66%
Conglomerate
Sandstone
Mudstone
Coal
lost core

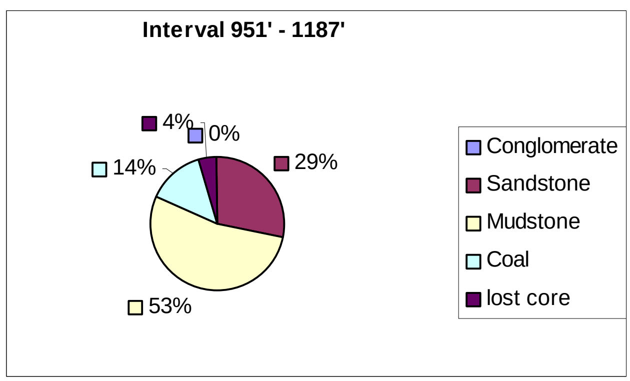

Interval 649' - 760'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core

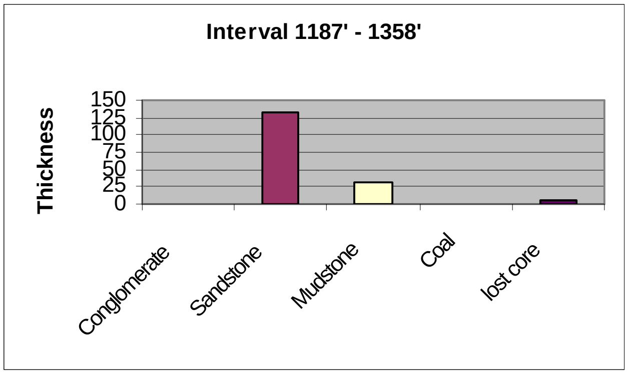

Interval 649' - 760'
4%
12%
5%
23%
56%
Conglomerate
Sandstone
Mudstone
Coal
lost core

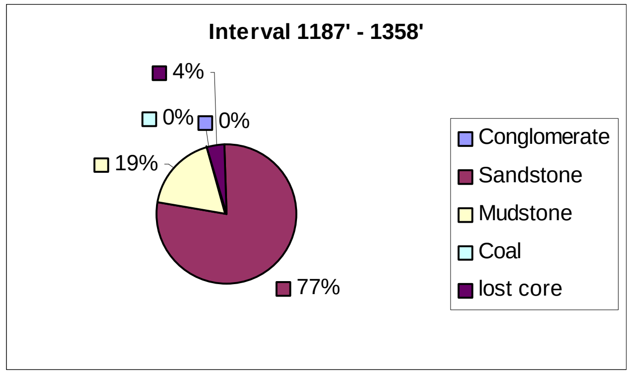

Interval 760' - 951'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core

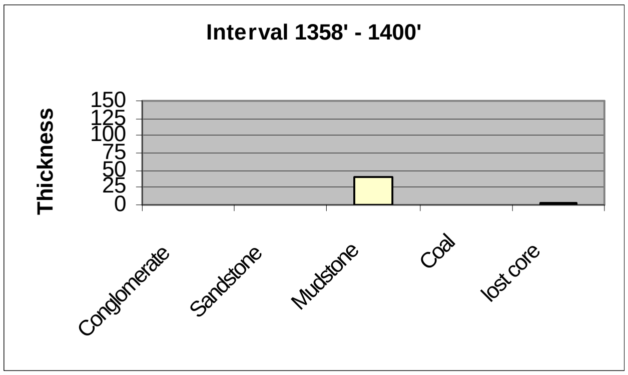

Interval 760' - 951'
11%
0%
2%
36%
51%
Conglomerate
Sandstone
Mudstone
Coal
lost core

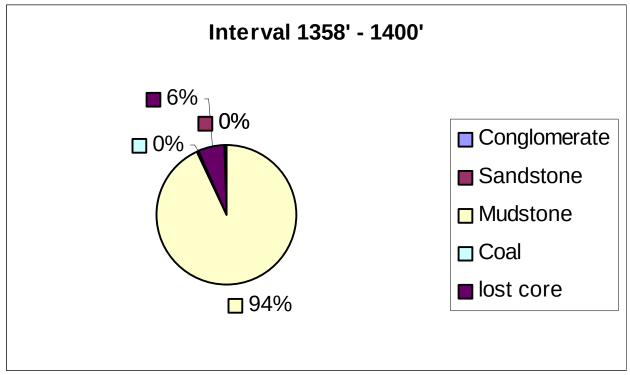

Interval 951' - 1187'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core

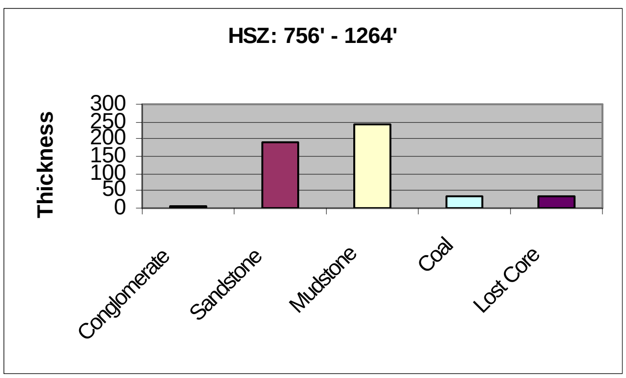

Interval 951' - 1187'
4%
0%
14%
29%
53%
Conglomerate
Sandstone
Mudstone
Coal
lost core

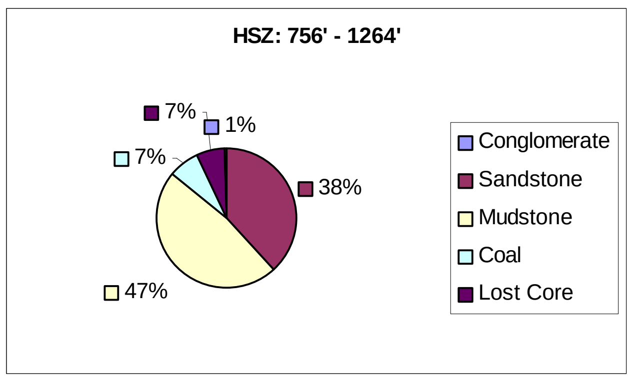

Interval 1187' - 1358'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core

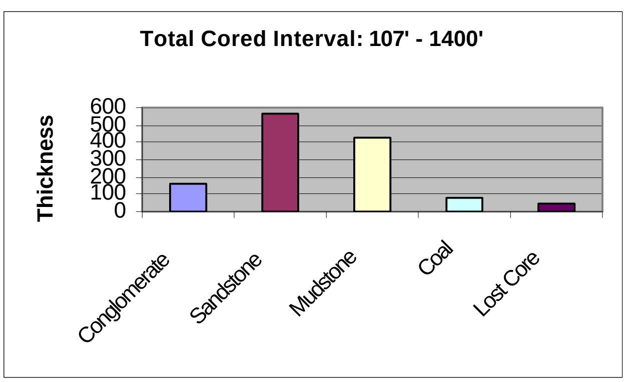

Interval 1187' - 1358'
4%
0%
0%
19%
77%
Conglomerate
Sandstone
Mudstone
Coal
lost core

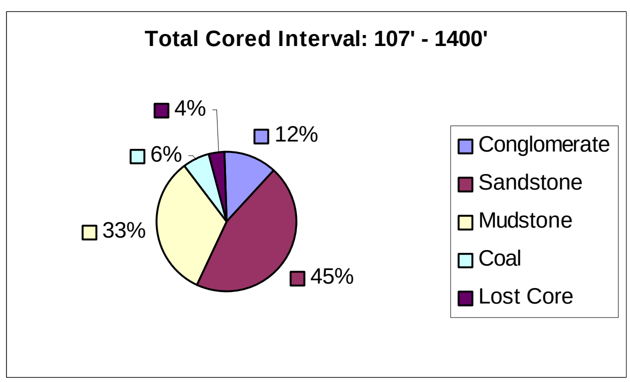

Interval 1358' - 1400'
Thickness
150
125
100
75
50
25
0
Conglomerate
Sandstone
Mudstone
Coal
lost core


Interval 1358' - 1400'
6%
0%
0%
94%
Conglomerate
Sandstone
Mudstone
Coal
lost core


HSZ: 756' - 1264'
Thickness
300
250
200
150
100
50
0
Conglomerate
Sandstone
Mudstone
Coal
Lost Core


HSZ: 756' - 1264'
7%
1%
7%
38%
47%
Conglomerate
Sandstone
Mudstone
Coal
Lost Core


Total Cored Interval: 107' - 1400'
Thickness
600
500
400
300
200
100
0
Conglomerate
Sandstone
Mudstone
Coal
Lost Core


Total Cored Interval: 107' - 1400'
4%
12%
6%
33%
45%
Conglomerate
Sandstone
Mudstone
Coal
Lost Core

Above this interval of sandstones and thin mudstones is dark gray or brown and black mudstone in which lenses of ice have formed along bedding planes. Above this mudstone is a black or dark brown lignitic coal, which also includes several ice lenses.

446 – 649 ft

The next deeper interval, 446 ft to 649 ft, is distinctive in comprising mostly conglomerate in beds as thick as 21 ft. The conglomerate beds are separated by thinner pebbly sandstones or sandy mudstones. Carbonaceous material is commonly present. The conglomerates consist of clasts of quartz, chert and lithic fragments of various types. Mudstone intraclasts also are common, most notably angular intraclasts of tan mudstone that probably are rip-up clasts, as they resemble some of the interbedded mudstones. Most of the conglomerates are clast-supported, but some more poorly sorted layers have sandy matrix support. Ice lenses are numerous in the interval 510-540 ft.

649 – 760 ft

The interval 649-760 ft is very different from the interval above. This is the most complexly interbedded interval in the core. It is marked by numerous thinner sequences consisting of conglomerate or sandstone grading upward into mudstone. This variability is reflected also in the thin sandy interbeds in the mudstones and thin mudstone layers in the sands. Above 730 ft, carbonaceous matter is very common, accentuating wispy horizontal laminations and low-angle cross beds in the sandstones. The interval is capped by a 9-ft thick mudstone and 6 ft of argillaceous lignite coal with ice lenses.

760 – 951 ft

The interval 760-951 ft includes several sequences of carbonaceous sandstone that become more argillaceous and grade into sandy mudstone above. In this aspect, the interval is similar to others above. One distinctive feature is the thin, 5-ft thick, oil-bearing sandstone beneath a 1-ft thick coal at the top of the interval. The oil in this sand is a heavy oil that does not “cut” with toluene solvent. Nevertheless, this occurrence is of interest, because it is the only such oil-bearing sand in the section cored.

Beneath a 3-ft thick coal at 835 ft, is a 48-ft thick, carbonaceous, sandy mudstone which contains fossil plant rootlets. Within this unit are several thin sandstone beds that have horizontal lamination or low-angle cross bedding. Numerous ice lenses occur in this mudstone.

In the deepest 50 ft of this interval (901 to 951 ft) is a sequence that is important because it marks a change in style of sedimentation. At the base of this unit is a mudstone that grades from slightly silty claystone below to sandy, silty mudstone, then upward to argillaceous, carbonaceous, very-fine-to-fine grained sand and finally, to fine-to-medium grained sand with low-angle cross bedding at the top. This is the first sequence of sediments exhibiting this motif of coarsening and "cleaning" upward that was encountered during the coring. It may signify an important change in the environment of deposition.

951 – 1187 ft

In this interval are several fining-upward sandstone/mudstone/coal sequences, as described above, but with occasional coarsening-upward sequences intervening. Intervals of each lithology tend to be thicker than the alternations cited above. At the top of the interval is a very thick (28-ft) lignitic coal. At the top, this coal is argillaceous with numerous ice lenses, and at its base are interbedded, carbonaceous mudstones and thinner coals. Below this, other sandier sediments and coal are present.

Between 1000 and 1076 ft, two prominent sandstones grade upward into sandy mudstones with thin coals. These sandstones are carbonaceous, and even contain small fragments of fossil wood. They have lenticular bedding and wavy laminae as well as horizontal bedding. Below thin coals the sediment commonly contains root traces.

The lower half of this interval, 1076 to 1187 ft, is predominantly mudstone. The few sandstones are very argillaceous. Very carbonaceous intervals of mudstone are common, and some exhibit color-mottling and root traces.

1187 – 1358 ft

This interval, in contrast to the one above it, consists mainly of sandstone. One prominent mudstone, 1226 ft to 1242 ft, is present, but otherwise, the frequent mudstones are very thin and sandy. The sandstones typically are fine-to-medium grained. They have horizontal or low-angle cross lamination. The sands are usually argillaceous, with occasional carbonaceous intervals. Some sands appear finer grained and more argillaceous upward, as others appear to coarsen and become less argillaceous upward.

An important aspect of this interval is that it includes the base-of-permafrost in this well at about 1260 ft. This coincides with a noticeable change in the mechanical properties of the cored rocks, as well as changes in the resistivity and acoustic wireline log responses.

1358 – 1400 ft

The top of this deepest interval cored is recognized as the base of the Ugnu sands, the informal stratigraphic unit described earlier. This interval is correlated widely as the unnamed mudstone unit between the Ugnu and underlying West Sak sands

(Runyon, 2003). The core of this interval comprises only monotonous, slightly silty mudstone with only a very thin coaly bed near the top.

The well had not completely penetrated this interval of mudstone when coring was halted and surface casing set to protect the permafrost. As mentioned previously, the well was then placed in suspended status.

Summary and Interpretation

A thick section of sandstones, mudstones, coals and conglomerates was cored continuously in the Anadarko Hot Ice #1 well during Phase I of the 2003 drilling program from 107 ft to current total depth of 1400 ft. At this depth the well was temporarily suspended because of an early thaw beginning on the North Slope. Surface protective casing was set at this point, just below the base of the ice-bearing permafrost. No gas-hydrate-bearing sediment had been encountered as of the suspension of coring.

Correlations with wireline logs and descriptions of cuttings taken in nearby wells lend support to the idea that the frozen sediments cored in this well are part of the Sagavanirktok Formation. The cored sediments are part of a thick sequence of rocks that are probably of late Cretaceous to early Tertiary age. Paleontologic evidence of this age is lacking, but stratigraphic position of these units and the absence of tectonic complications in this area of the North Slope support this age assignment. Like similar sequences studied in nearby outcrops of the North Slope, they have characteristics of marginal marine or deltaic deposits. Some authors refer to these sequences as the "Deltaic Unit" of the Brookian Sequence (Molenaar, 1983), referring to their origin as part of the deposits transported from the south and southwest to fill the tectonic basin that formed with uplift of the Brooks Range. If these correlations are correct, then the bottom of the cored interval at 1400 ft was in the mudstone that separates the Ugnu sands from the underlying West Sak sands, informal members of the Sagavanirktok Formation.

The thick mudstone at the base of the cored interval, 1358–1400 ft, may be a marine tongue of fine grained sediment representing a brief transgression of the late Cretaceous sea over the mostly terrestrial environments of this area. Sandy sediments above this mudstone are thin sequences that form alternations of fining-upward and coarsening-upward units. They become very carbonaceous upward and are capped by a thick coal and mudstone interval. This overall interval includes a prominent, very sandy and carbonaceous mudstone unit more than 100 ft thick. These sequences, from 951 ft to 1358 ft, probably represent the attempted, repeated progradation of several wedges of sandy sediment from the southwest into a more marine environment to the northeast. These progradations culminated in the persistent presence of coal-forming environments in this area, such as coastal marshes and delta-top swamps, which resulted in the thick coals at the top of the sequence.

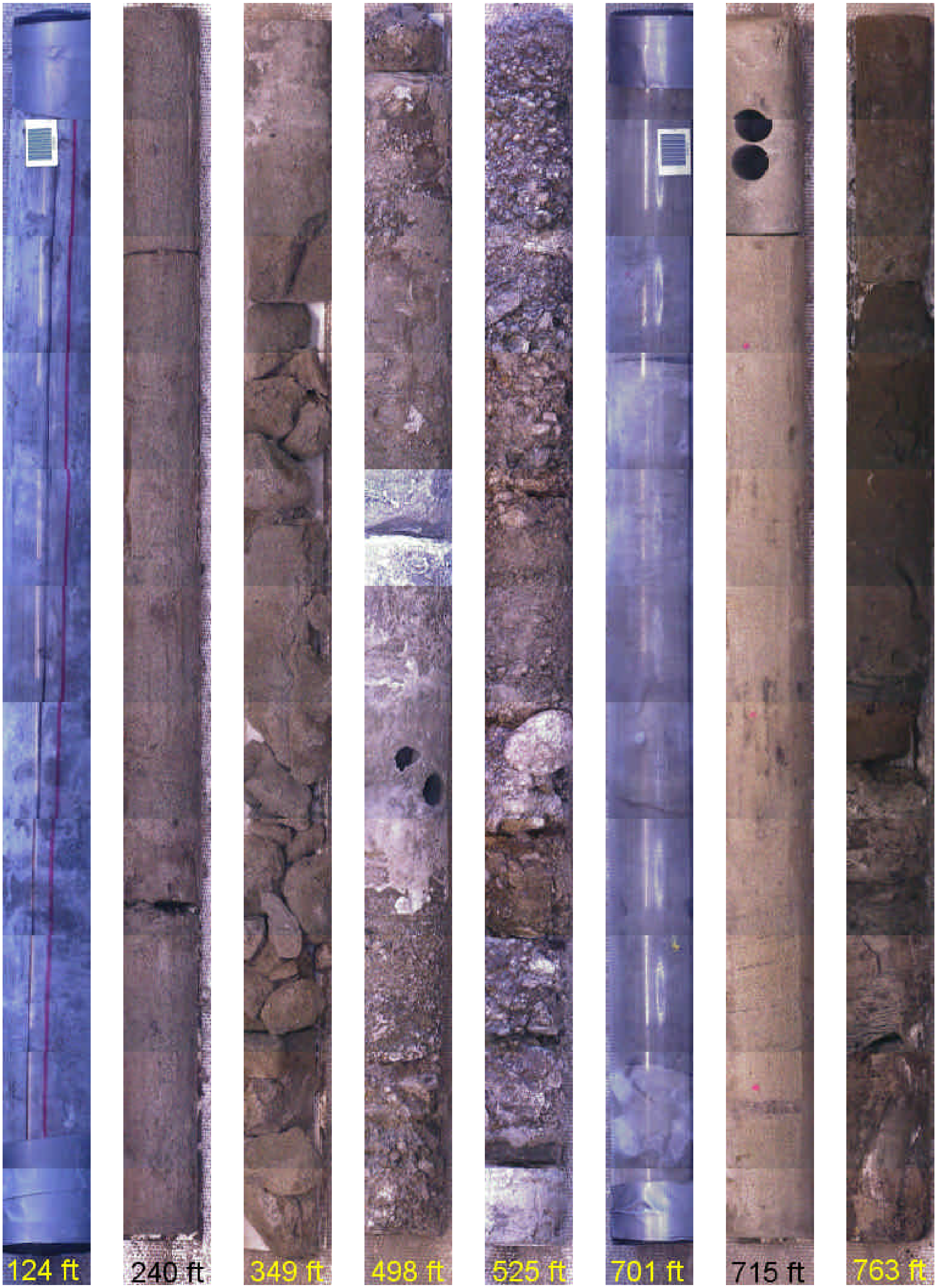
Following this time of coal formation, sand and mud sedimentation resumed, and the first 50 ft of deposits above the coal were a coarsening-upward sequence of sandy mudstone and sandstone. Following deposition of these units, however, the alternations of finer grained and coarser grained sediments mostly followed the pattern of fining-upward. These patterns suggest deposition of distributary mouth bars and crevasse splay sediments, which prograded over a subsided area of coastal swamp environments. These deposits were then buried by deltaic distributary and overbank sediments as shallow water deltas worked over the prograding coastal plain. Another coal, 6 ft thick, was deposited at the top of these sediments, attesting to the natural variability inherent in coastal plain deposits. This sequence of events is represented by the sediments cored from 649 ft to 951 ft.

After this period of sedimentation when alternations of coarser and finer grained sediments were so common, a thick sequence of mixed-clast conglomerates was deposited in this area, seen in the sediments from cores of the interval 446 ft to 649 ft. This would seem to represent a time of maximum progradation of the onshore, terrestrial environments of deposition, such as when short-headed, high-energy streams could have crossed a very narrow deltaic shelf and/or when there was increased tectonic activity in the source area to the south and southwest, as suggested by Molenaar (1983). This would have resulted in very coarse sediment being delivered to this area of deposition.

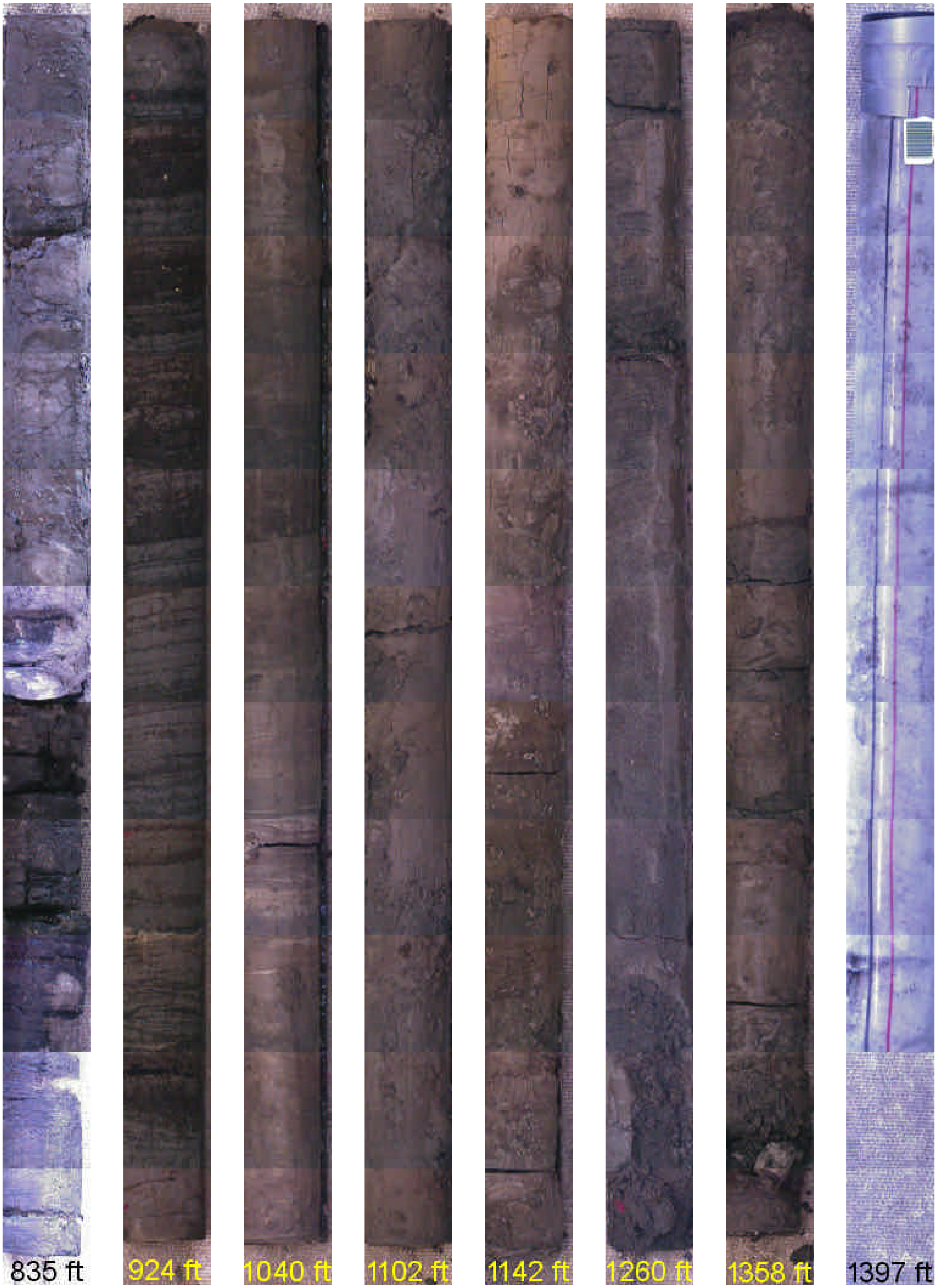
The next phase of sedimentation in this area resulted from return of more typical upper deltaic environments, with fluvial sequences being dominant over the area, represented by cores from 143 ft to 446 ft. The earlier of these sediments may have been deposited by braided streams, as they contain basal units of pebbly, coarse sand, grading upward into finer grained sediment. Higher in the section, the sandstones are fine-to-medium grained, also grading upward into sandy mudstones. Two prominent coals occur within and at the top of this interval of fluvial sediments, again suggesting the shifting nature of environments of deposition and re-establishment of peat swamps and lakes or other very low energy environments in this area.

Finally, just above the uppermost coal is a thick mudstone from 114–143 ft which may represent another incursion of marginal marine conditions over the low-relief, coastal or freshwater swamp environments represented by the underlying coal. Above this mudstone are a few feet of conglomerate, stained dark by carbonaceous material from above, that probably represents the near surface gravel of the Gubik Formation, of Tertiary age.

Representative Core Sections from Hot Ice #1 Well

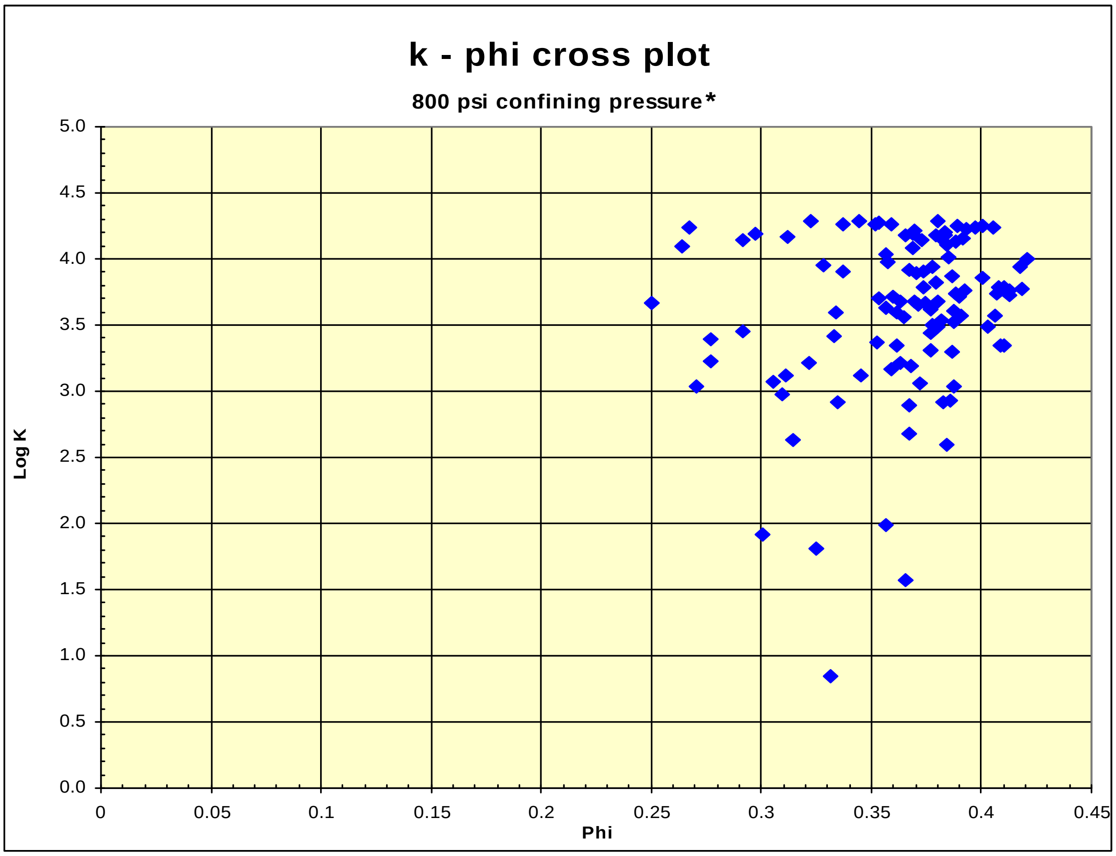


Representative Core Sections from Hot Ice #1 Well



Porosity and Permeability Measurements (by R.F. Sigal, Anadarko)

Porosity phi and permeability k measurements have been made on 1-inch diameter plugs taken from the sandstone section. The geologic description was used to select sample locations. The accompany k-phi cross plot shows that the sands are very high porosity, mostly between 30 and 40%, when measured at 800-psi confining pressure. At 800-psi confining pressure almost all the measured permeability values are greater than 1 Darcy with many over 10 Darcies. These are unconsolidated sands so porosity and permeability are both pressure dependent. Large permeability losses (some in the range of 50%) were seen when confining pressure was increased to 1800 psi. Porosity losses tend to be near 10%.



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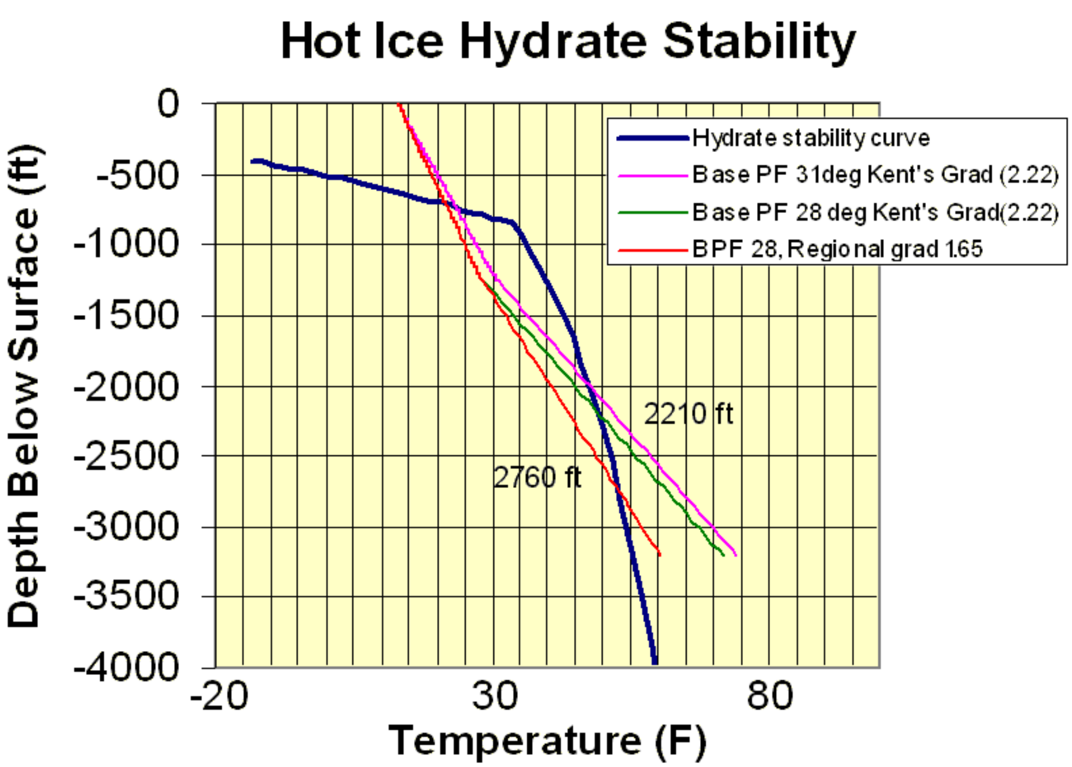
Appendix D. Recalculation of Base of Hydrate Stability Zone

Information from the Hot Ice well and an analysis of the local geothermal gradient provided a new estimate for the base of the hydrate stability zone (BHSZ). This re-analysis places the BHSZ at **2210 ft** below the surface at the Hot Ice location. This is 400 ft shallower than the estimate based on regional maps from Collett et al. (1988).

Both core and log data show the well entering into unfrozen material at 1240 ft below the surface at the Hot Ice location. The base of frozen material occurs in a thick sand interval. Because of this, 1240 ft is the base of permafrost. The BHSZ then depends on temperature at this depth, thermal gradient, and the methane hydrate stability curve. Collett et al. find the average temperature at base of permafrost to be 28°F. The BHSZ only weakly depends on the exact temperature chosen within the possible range of values. The most important variable is the thermal gradient.

Newsham (Internal Anadarko Report) examined logs from West Sak 20 Cirque 2 and Ruby State 1. Using the log-identified base of permafrost, corrected bottom hole temperatures, and a temperature at base of permafrost of 28°F, he finds a local thermal gradient of 2.22°F per 100 ft. The most critical part of this calculation is the correction to the log-recorded bottom hole temperature. Newsham corrected the bottom hole temperature data using the diffusion model documented by Lachenbruch et. al. (1982). This local gradient is somewhat larger than the regional gradient of 1.65°F per 100 ft given in Collett et al. (1988). The figure below shows the BHSZ determination using both gradients and two possible temperatures at the base of permafrost.



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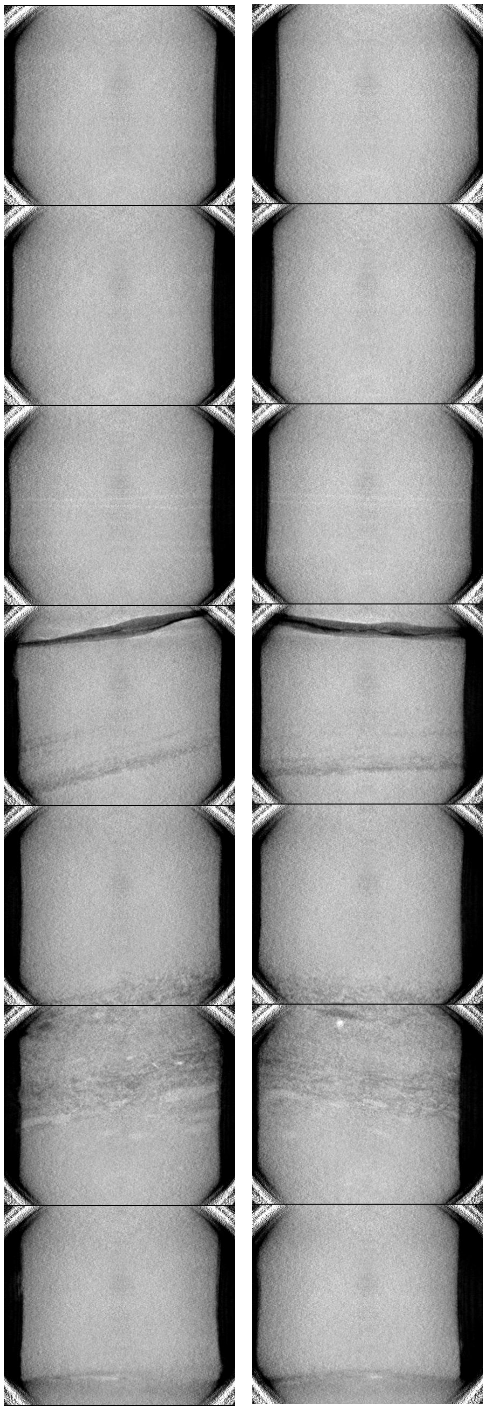
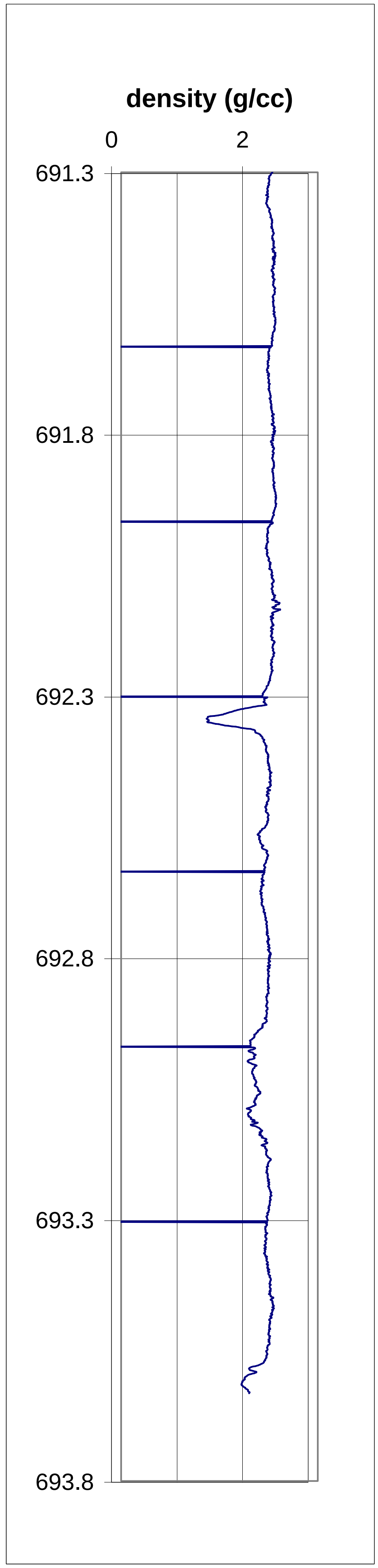
Appendix E. X-Ray and Density Log Data from Hot Ice Well

Presented here are x-ray images compiled into mosaics of three different cores from Hot Ice #1. Plotted next to the images is the average density across the middle of the core tube. These figures show the lithology; however, the actual data files are much more detailed and will not reveal the detail available until they are shown at considerably higher resolution.

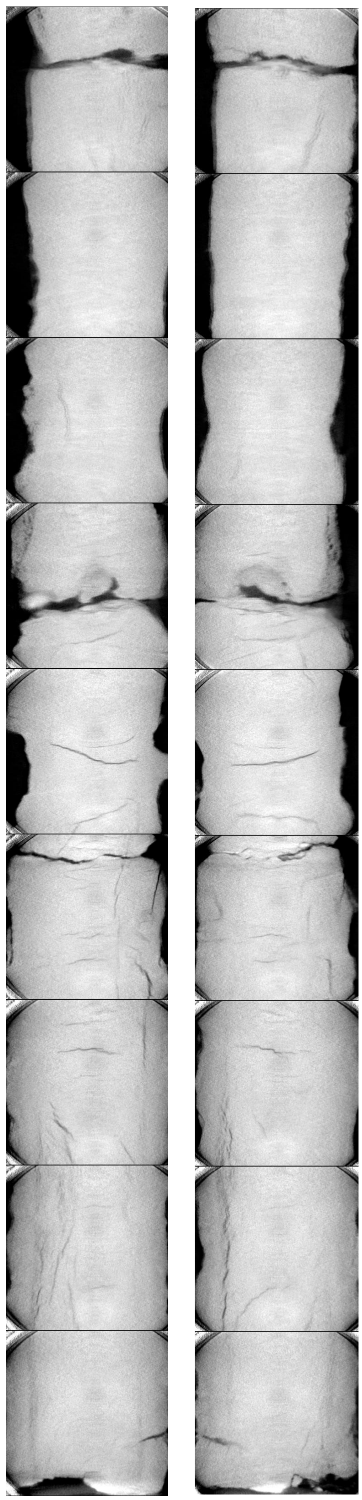
There are many other ways to consider the x-ray data. Shown are two slices through the core tube that are orthogonal to each other. Other options include a sequence of parallel or rotated images; these can also be produced from these data. Two perpendicular images give the most information about the dip of bedding planes in the smallest space.

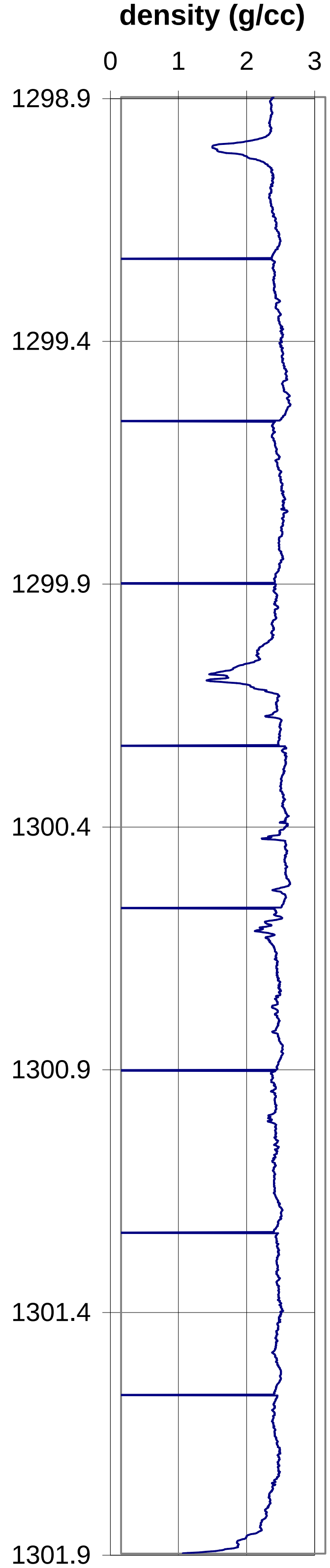
Hot Ice #1 Tube 181



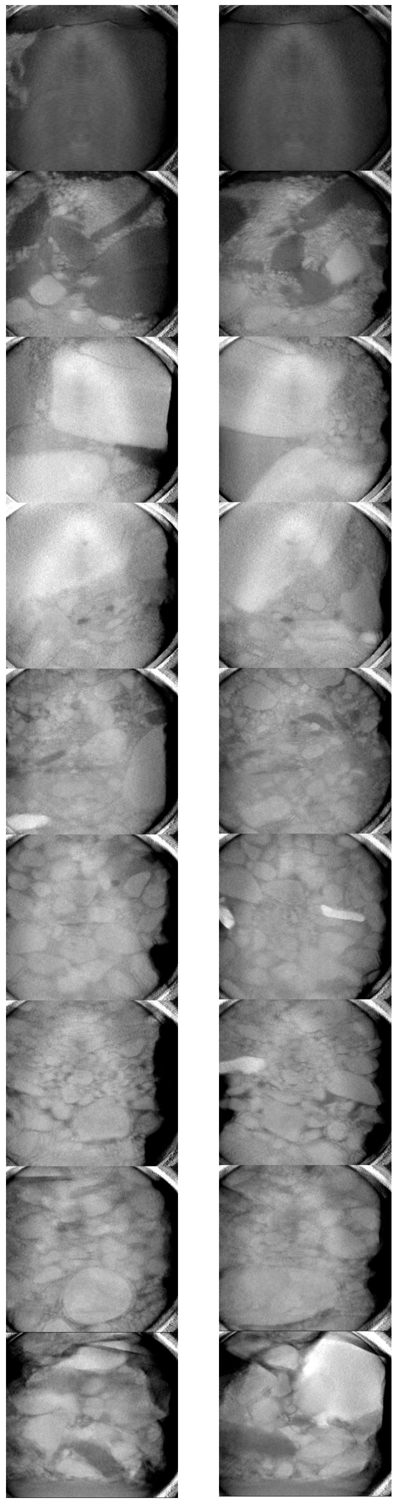


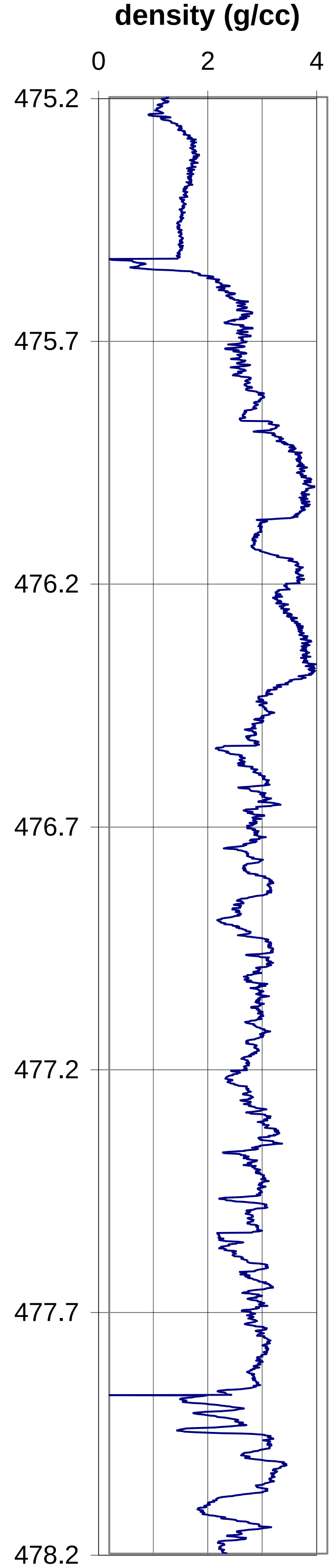
Hot Ice #1 Tube 181





Hot Ice #1 Tube 181





Appendix F. Physical Limitations on Coalbed Gas Content of Low Rank Coals, North Slope, Alaska: An Apparent Widespread Depletion of Coalbed Gas in Permafrost

Charles E. Barker, USGS, Denver; James G. Clough, Alaska Division of Geological and Geophysical Surveys, Fairbanks; Stephen B. Roberts, USGS, Denver; Arthur Clark, USGS, Denver, and Bob Fisk, BLM, Anchorage

The best known coal occurrence on the North Slope, Alaska is the western Colville sub-basin. This basin contains Alaska's greatest coal deposits, with up to 150 significant coal seams that range from 5 to 28 ft in thickness and cover an area of some 40,000 mi^2. Near the city of Wainwright, the Nanushuk coals have a rank of 0.4% mean random vitrinite reflectance (Rv-r) at the surface and increase to about 0.6% Rv-r at the base of the coal-bearing rocks at 2000 ft. At this depth, adsorption isotherm analysis indicates a gas storage capacity of 80 scf/ton (as-received basis) if the coal is saturated.

Another significant coal zone in the North Slope Basin is the Tertiary Sagavanirktok Formation. Geophysical logs indicate that Sagavanirktok coals underlie about 2000 mi^2 from below the Prudhoe Bay area to ~70 miles south, where they crop out. Sagavanirktok coals are 0.3% Rv-r at the surface and increase at 0.05% Rv-r/1000 ft depth. The best coal-bed methane (CBM) prospect is the lower coal zone that contains up to 160 net ft of coal, with individual 30-ft thick coal beds, that reaches a depth of 6000 ft below Prudhoe Bay area.

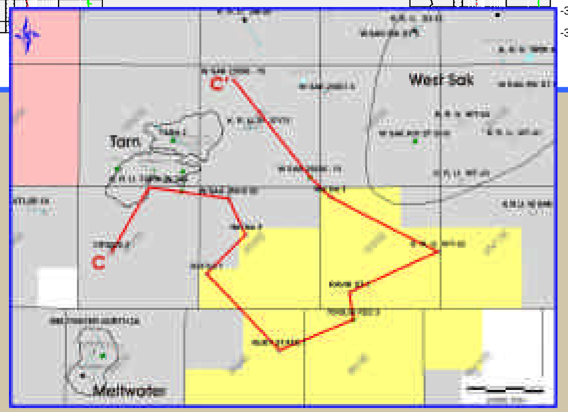
Preliminary resource assessments by several research groups indicate a geologically-based gas in place of hundreds of TCF of CBM in the North Slope Basin. New data and reinterpretation of old studies suggest that this large gas-in-place estimate is strongly limited by depletion of CBM in the permafrost. In the coastal portions of the North Slope basin, permafrost thickness is about 1000-2000 ft. Depletion of CBM in the permafrost alone could reduce total CBM gas resource by as much as 25 to 50% above 4000 ft depth. The lack of CBM in permafrost is attributed to: 1) reduced microbial methanogenesis at low temperature; 2) interception of gas migrating upward from deeper basin sources by gas hydrate formation below the base of the permafrost; and 3) permafrost formation physically disrupting gas traps and seals by water-injection fracturing at depths up to 1000 ft.


Legend of General Symbols
Ground elevation is 188.0' above MSL. The KB elevation is 26' above ground level, or 214' above MSL. All log depths are from KB.
Gravel: quartz & lithic, very coarse to pebble, angular to subrounded, black carbonaceous matrix; contains a thin bed of medium to coarse grained sandstone, moderately sorted, subrounded, with occasional pebbles
Mudstone, w/ a few silty lenses, more silty toward base, horizontal lamination.
Thin beds of granule and v. coarse sand interbedded with sooty black mudstone and lignite.
Coal (lignite), black, sli. muddy, w/ few scattered pebbles.
Alternations of sli. sandy mudstone and impure lignite
Clay/Mudstone: medium to dark-gray, firm, occasional sand grains and carbonaceous layers
Coal: black, very low grade, argillaceous, occasional pebbles and sands streaks
Clay/Mudstone: dark gray to dark brown, firm, very carbonaceous
Coal: overlying carbonaceous clay grades downward into argillaceous coal, black, firm, with a thin clay layer at 176.6'
Clay/Mudstone: gray-brown to medium gray, firm, carbonaceous at the top but decreases downward becoming more sandy with distinct sand layers and grades to more medium gray color with depth
Clay/Mudstone: mostly medium to some light gray, soft and sticky to firm, sandy throughout, grains are mostly medium with some coarse
Sandstone: light to medium gray, very argillaceous, moderately sorted, some pebbles in the lower 0.5' of the lower bed, interbedded with sandy clay/mudstone
Clay/Mudstone: medium and light gray, firm, slightly sandy, very finely laminated
Sandstone: medium gray, firm, mostly coarse with scattered lenses of medium grained, argillaceous, some scattered pebbles
Sandstone: medium gray, medium grained with some finer grained downward, firm, moderately sorted, subrounded, argillaceous, dark lithic grains give salt & pepper appearance
Sandstone, gn-gy, fine to medium, few shaly laminae
Sandstone, gn-gy, fine to medium w/ scattered pebbles
Sandstone, gn-gy, fine to medium, very even-textured, slightly argillaceous.
Conglomerate, med. gy., very poor sorting, fine to coarse sandy matrix
Sandstone, gn-gy. very fine to medium, carbonaceous and coarsening to med.-coarse downward.
Coal, black or dark brown, lignite, few sandy lenses. several ice lenses each about 0.1' thick; no sample 254.7-255.
Mudstone, dark gray, brown and black, firm, with occasional ice lenses on bedding.
Sandstone, gray green, medium-coarse, friable to firm, moderately sorted, argillaceous at top, cleans downward.
Alternations of very fine sandstone, siltstone, mudstone and occasional medium grained sandstone, gray green, argillaceous
Sandstone/Silt: interbeds of medium-coarse, very fine-fine sandstone and siltstone, dark gray geen, friable to firm, finer grained rocks increase downward
Siltstone and very fine-grained sandstone, argillaceous.
Alternations of medium to coarse Sandstone with finely bedded Mudstone and very-fine to fine Sandstone.
Sandstone, medium to coarse, silty in lower part.
Mudstone, with very-fine sandy laminae.
Thick section of medium to coarse grained Sandstone, with gradations of grain size throughout, grading often into numerous thin Mudstone layers in fining upward sequences; coarser sandstones have low-angle X-beds, mudstones have concentrations of carbonaceous matter on laminae.
Sandstone, grades F to M, or F to C, in 2 - 3 sequences, sli. argill. near base, core partly rubble.
Mudstone, silty and sandy, w/ few large clasts of M-C SS.
Sandstone, F - VF, carbonaceous at top
Mudstone, v. stiff, dense, not silty or sandy
Mudstone, olive gray, v. stiff, ice in thin lenses
Sandstone, VF - M, argillaceous, carbonaceous on low-angle X-beds.
Sandstone, brn-blk, VC-C, lignitic, poor sorting.
Sandstone, M, well sorted, carbonaceous laminae on high-angle X-beds
Conglomerate, mixed clasts, sandy matrix support, some pebbles up to 0.2', very poor sorting, clasts angular to subrounded.
Mudstone, slightly sandy with occasional 0.1'-0.2' sandstone lenses: 0.1' thick ice lens occurs at top
Sandstone, medium to coarse grained, locally grading to more medium grained and moderately well sorted; scattered pebbles; horizontal beds; slightly carbonaceous.
Sandstone, becoming more coarse grained with common pebbles
Mudstone, 0.2' thick
Conglomerate, granule and pebble sized, with very coarse Sand, mixed clasts of lithics, quartz and clay; very poorly sorted, angular to rounded; some clay clasts up to 30mm
Mudstone, sandy (medium to coarse); sticky
Sandstone, medium to coarse, with carbonaceous and mudstone laminae, low-angle X-beds, few light creme to light tan, rounded claystone clasts below 452.4'.
Conglomerate, mixed clasts, with some cobble size light tan claystone clasts.
Sandstone, medium to coarse, with light tan clay clasts; clasts increase downward to zone of predominantly brown, dark gray and tan clasts
Conglomerate, granule to pebble, mixed clasts, no clay clasts.
Sandstone, medium to coarse; sharp contact with overlying conglomerate
Conglomerate, granule - pebble size, mixed clasts; Sandstone lens at 471.8', several large claystone clasts below 472'.
Claystone, lt. tan, same as clasts up-hole, separated from medium to coarse sandstone below by a thin layer of pebbles..
Conglomerate, mixed clasts, occasional clay clasts, scattered thin (0.1'-0.2') sandstone and clay layers
Large clay clast (90mm) at 489.5'
Sandstone, light tan lens with carbonaceous laminae
Sandstone and mudstone in alternating fining-upward sequences, grades downward into gravel below; upper mudstone is light tan at top and grades to dark gray downward
Conglomerate, granule and pebble sized, mixed clasts; thin, dark gray mudstone at 505'; few tan claystone clasts near base.
Mudstone, light tan at top, darkens to black at base, slightly sandy; scattered ice lenses in horizontal lamination.
Conglomerate, mixed clasts, sandy matrix.
Sandstone, medium to very coarse, pebbly at 518.8', abundant cobbles and clay clasts 520.9'-522.7'
Conglomerate, mixed clast, matrix supported, few carb. lam., few ice lenses
Mudstone, silty and sandy, firm, horiz. laminae of F-VF Sd.,few carbonaceous laminae, 2 ice lenses.
Conglomerate, mixed clasts, pebble-supported, fine sandy mtx., v. muddy in top 0.5 ft. v. hard, ice lenses and "cement". Most of clasts are lithic fragments and chert, with some SS and Slst. clasts. Few thin well sorted pebble layers, but most of core is very poorly sorted.
Mudstone, silty w/VF white shell frags.(?)
Sandstone, VF-F, silty, v. even texture, horiz. carbonaceous laminae.
Conglomerate, mixed clasts, clast-supported, coarsest at 564-565'
Sandstone, very silty, very carbonaceous in lower 2/3, low-angle inclined laminae
Conglomerate, mixed clasts, very sandy, grain-supported, w/few very large clasts and few sand mudstone layers, very poor sorting overall.
Alternations of sandy conglomerate, silty sandstone and mudstone, with sharp contacts, not gradational.
Conglomerate, mixed clasts, clast-supported, sandy
Mudstone, tan in top 0.3', gn-gy. below; thin VF-F sand bed at 602.4'
Conglomerate, very sandy, mixed clasts, clast-supported.
Mudstone, silty, with laminae of silt and VF Sand in bottom 0.5'
Sandstone, coarsens downward to granules at base; 0.1' coal at base
Conglomerate, v. sandy and silty matrix, coarsens downward
Sandstone, VC-M, scattered pebble layers, carbonaceous at top.
Conglomerate, mixed clasts, v. sandy, matrix supported, scattered carbonaceous fragments, sandstone lens at 636.7'
Sandstone, C - M, even textured
Coal, black, lignite, fractured, with ice lenses in fractures and displacive along bedding.
Mudstone, dark gray green, finely laminated, becomes more sandy and lighter (medium gray green) downward
Interbedded sequence of dark gray to black, mostly fine grained sandstone, siltstone and mudstone, finely laminated; carbonaceous layers
Sandstone, dark gray green, fine to medium grained, with laminae and thin beds of mudstone and carbonaceous laminae
Sandstone, dark gray green, mostly medium grained, scattered organic layers and rare ice lenses in sub-horizontal fractures; mudstone rip-ups at 679.6'
Sandstone, fine grained, fines upward to siltstone and mudstones of overlying units; low-angle X-laminae; sub-horizontal ice lens
Mudstone, dark gray green, firm, with thin interbeds of fine sand, siltstone and carbonaceous layers
Sandstone, dark gray green, medium grained, low angle cross bedding marked by wispy organic laminae
Mudstone, with fine laminae of fine grained sand, silt and organics
Alternating Sandstone and Mudstone, thinly bedded or laminated, with common carbonaceous material; some low-angle X-beds in sands; small, tan clay clasts
Sandstone, dark gray green, fine to medium grained, horizontal bedding, some carbonaceous material on wispy laminae; core of lower part of section is rubble.
Mudstone and Sandstone interbeds, 0.1-0.2' thick, scattered pebbles
Conglomerate, large mixed clasts, clast-supported, claystone clasts common, very poorly sorted pebbles.
Sandstone, VF-M, coarsens downward, v. carbonaceous in top 1.2'; irregular contact with thin mudstone below.
Conglomerate, mixed clasts, grain support, poor sorting
Mudstone, silty, w/ laminae and thin beds of VF-F sandstone.
Conglomerate, mixed clasts, v. sandy
Mudstone, sli. silty, with thin pebbly layers of rounded clasts and thin sandstone beds.
Sandstone, M., w/scattered pebbles and larger clasts of tan siltstone at contact with overlying sediment.
Sandstone, VF-F, alternating with thin mudstone beds.
Conglomerate, very poor sorting, muddy, alternating with M-C Sandstone w/pebbles; yellow-stained interval at base, above
Coal, black, very hard, fractured
Sandstone, F-M, even textured, dark brown w/black mottling, root traces in top, brown color due to OIL STAIN. Oil appears to be heavy-oil; small amount of gas evolves from pores; no cut in solvent; oil stain diminishes below 764.8'; as is more argillaceous with carbonaceous streaks below 765.2'
Mudstone, very dark gray to mostly black, carbonaceous
Sandstone, dark gray, fine to medium grained, fine horizontal laminations of sand and organics,
Mudstone, dark gray and gray brown, very sandy at top, decreasing downward, fine sand, silt and organic laminations throughout
Sandstone, upper part F-VF w/horiz. bedding, grades down to M at 797.7' w/ high-angle X-beds and to wavy bedded w/mudstone clasts below 800.3.
Mudstone, sli. silty, lens of coal at 804.4';
Mudstone, soft (thawed), w/ thin sandy interbeds
Sandstone, soft (thawed), w/ thin claystone interbeds.
Sandstone, M-F, hard, badly fractured in core barrel
Sandstone, VF-F, silty w/ carbonaceous laminae; thin ice lens
Coal, fractured top w/ ice lenses in fractures, horiz. layering below
Mudstone, sli. silty, sli. carbonaceous, w/ thin, irregular tan streaks near base, horiz. bedding.
Sandstone VF-F, carbonaceous laminae
Claystone, carbonaceous flecks and a long root cast at 859'.
Sandstone, dark gray-green, very fine to fine grained, very finely laminated horizontal bedding
Mudstone, medium to dark gray and gray green, sandy (v.f.) and silty in part, finely laminated horizontal to low angle cross bedding, roots, root casts and some light tan lenticles suggesting oxidation, ice lenses occur on 1 to 2 foot intervals
Sandstone, dark gray green, mostly fine grained with thin laminations of medium to very coarse at the bases of sequences which grade up to siltstone and rarely mudstone
Mudstone, very dark gray to black, carbonaceous, very slightly sandy (v.f.) or silty, no root zones
Sandstone, very dark gray green, fine to some medium grained, numerous thin mudstones and organic layers in top 3', occasional low angle cross beds
Mudstone, dark and medium gray with some light tan zones, thin organic layers and very fine sands in upper part, some low angle cross beds, becomes massive below 898.8' without sand
Sandstone, dark gray, very fine to fine grained, up to medium in some zones, finely bedded, 2-3 mm laminations, black organic layers, thin mudstones near top, low angle cross bedding
Sandstone, dark gray, very fine- to fine-grained, occasional medium grained, black organic layers, thin mudstones
Mudstone, dark gray, occasional light gray and tan layers, very sandy with thin sandstone and siltstone interbeds, thin organic layers throughout,
Mudstone, becoming more massive and less sandy toward base
Sandstone, medium gray, fine grained, with dark root traces and organic flecks
Coal, brown and black, lignitic to sub-bituminous, with thin (0.1'-0.2') sandstone and mudstone interbeds, and ice lenses
Mudstone, dark gray to black, local tan zones due to root traces, fine-grained sandy in part, ice lenses
Coal, black, sub-bituminous, argillaceous in part, and scattered mudstone layers, ice lenses
Mudstone, tan at top,grading down to very dark gray to black in organic layers
Mudstone and Coal, interbedded, mudstone is carbonaceous w/ root traces and coal is argillaceous.
Mudstone, silty w/ root traces and carbonaceous fragments.
Sandstone, medium gray, mostly fine grained with some zones of medium grained, argillaceous with organic laminae and thin mudstone beds throughout,
Mudstone, dark gray, massive, non-sandy, non-carbonaceous
Coal, black, argillaceous at top
Mudstone, silty, sli. sandy, coaly at top, becoming more sandy downward.
Sandstone, F-VF, v. argillaceous, w/ mudstone laminae and thin (0.2'-0.4') beds;sli. carbonaceous; low-angle X-beds and wavy laminae at 1011'-1014'.
Sandstone, F-VF, vague horizontal bedding, very uniform texture.
Siltstone, v. argillaceous, sandy, contorted bedding.
Sandstone, VF-F, v. argillaceous and carbonaceous, lenticular bedding and horiz. lamination, fines drape sandstone lenticles.
Claystone, v. carbonaceous w/ thin lignites
Coal, fractured, lignite
Claystone, black grading to yellow downward, many rootlet traces, carbonaceous
Mudstone, silty and w/ VF-F sandy thin interbeds
Sandstone, M-F, well sorted, wavy bedding.
Mudstone, w/ silt and VF sandy lenticles and laminae
Sandstone, F-VF, horiz. bedding w/ occas. wavy laminae or low angle cross (ripple?) laminae; at 1048.9'-1049.3' are small brown wood fragments.
Sandstone, VF, silty, w/ thin (0.1'-0.4') tan mudstone beds; Mudstones are hard and waxy in upper half, but softer and silty in lower half; tan mudstone intraclasts at 1062.3'; horizontal bedding.
Sandstone, dark gray, very fine- to fine-grained, silty in part, massive with little indication of bedding, occasional carbonaceous wood or coal fragments
Mudstone, very dark gray to black, sandy in part, tan cemented root traces and layers, massive in upper part, finely bedded below 1080'.
Coal, black, sub-bituminous, argillaceous at top and base, thinly bedded throughout
Mudstone, mostly dark gray and dark brown, with occasional light gray, gray green and tan layers (0.25'-0.5"), becomes very carbonaceous below 1095.8'
Mudstone, dark gray and dark brown, carbonaceous zones end and sand begins increasing at 1098.6', sand increases downward until it predominates at 1112.1.
Sandstone, dark gray geen, mostly very fine- to fine-grained, medium in part, very argillaceous at top, cleans downward to 1116.6' where mudstone layers become infrequent
Mudstone, dark brown to dark gray, massive at top becoming thinly bedded and laminated downward with increasing very fine sand and silt layers below 1121'; sand increases until it predominates at 1123.2'
Sandstone, dark gray green, very fine- to fine-grained, very argillaceous at top with mudstone interbeds, mudstone decreases slightly with depth
Mudstone, dark brown to dark gray, sandy and silty at top, carbonaceous, especially at 1130.8' and 1132.5'-1133' w/ thin coaly beds
Mudstone, silty, thin VF sandstone interbeds.
Mudstone, silty, carbonaceous, rooted intervals w/ yellow mottling, thin (0.1'-0.4') sandy interbeds at irregular intervals.
Mudstone, silty, gray/brown mottling, few elongate black root traces; no sandy interbeds.
Sandstone, dark gray green, fine to medium grained, very argillaceous, root zones, carbonaceous layers, occasional quartz pebbles
Mudstone, light to dark gray, very sandy, gradational to overlying lithology, carbonaceous zones
Sandstone, dark gray green, very fine- to fine-grained, argillaceous but no distinct mudstone layers
Siltstone, medium to dark gray, massive to thinly bedded, grades downward from sandstone above over a thin transition zone (0.3')
Sandstone, dark gray, medium grained, mostly massive, very indistinct bedding (core preservation ?), occasional rounded quartz granules and pebbles, coal fragments; becomes very argillaceous below 1305.5'
Sandstone, dark gray, medium grained, occasional thin mudstone layers, sandstone alternates between relatively clean and argillaceous
Mudstone, dark gray, slightly sandy at top but increasingly sandy downward, some very fine-grained sandstone interbeds near the base
Sandstone, dark gray green, fine to medium grained, fairly clean with distinct mudstone layer at 1339.5'
Sandstone, M-F, well sorted, carbonaceous, bedding not clear.
Mudstone, silty, laminated, w/ thin (0.1'-0.3') VF-F sandstone interbeds at irregular intervals.
Sandstone, F-M, laminated with carbonaceous matter in upper half, but more featureless below.
depth correction
Mudstone, sli. silty, horizontal bedding, 0.1' coal at 1360.7', and thin (0.1') sandstone bed above the coal; rest of section all mudstone.
Description

HOT ICE PROJECT

Cross-section C-C'

Anadarko Petroleum Corporation



Hydrate Bearing Interval

Potential Hydrate Bearing Interval

Free Gas Bearing Interval

Potential Free Gas Bearing Interval